ONLINE APPENDIX
Dual Use Deception: How Technology Shapes Cooperation in International Relations

Reference: Jane Vaynman and Tristan A. Volpe, "Dual Use Deception: How Technology Shapes Cooperation in International Relations," *International Organization*, Vol. 77, No. 3 (Summer 2023), https://doi.org/10.1017/S0020818323000140.

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Part I: Scoping the Universe of Technology Cases

Our universe of cases includes all technologies that states have used to arm themselves with distinct weapons or weapon platforms in the modern era. We date the modern era for technology around the industrial revolution, which historians commonly agree began in 1760 with the rise of mechanized textile manufacture.[1] This inclusion rule reflects the phenomenon we seek to explain: state efforts to negotiate controls over the possession or use of military armaments.[2] In this part of the appendix, we define each term in greater detail to establish clear inclusion and exclusion rules for the case universe.

Inclusion Rules

A *weapon* refers to an object used to inflict injury or damage upon enemy personnel or materiel. We narrow this definition to include weapons that have been deployed by nation states in the modern era. The term encompasses a range of capabilities with discrete damage effects, from conventional explosives to network attack tools. A *weapon platform* is a combination of one or more weapons with a vehicle or delivery system that can reach enemy targets. Thus, naval vessels and rockets can be platforms for hosting or delivering various weapons. Given our focus on arms control, we restrict both terms to include weapons and weapon platforms that enjoyed operational use during the modern era.[3] These twin definitions establish the inclusion rules for our case universe around weapons and weapon platforms. We draw boundaries around technology categories based on the features that make each weapon or weapon platform unique. In cases where the technology is open to multiple definitions, we also consider whether different categorizations could change coding of the dual use attributes.

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[1] See Thomas S. Ashton, *The Industrial Revolution: 1760–1830* (Oxford, UK: Oxford University Press, 1948); Louis C. Hunter and Lynwood Bryant, *A History of Industrial Power in the United States, 1730–1930, Vol. 3: The Transmission of Power* (Cambridge, MA: MIT Press, 1991). In a few cases, we trace the antecedents of modern technology back before this time to explore how the weapon or platform evolved in ways that shaped the dual use dimensions.

[2] This widely accepted definition of “arms control” comes from Thomas C. Schelling and Morton H. Halperin, *Strategy and Arms Control* (Potomac Books, 1961), 3. See also Heather Williams, “Asymmetric Arms Control and Strategic Stability: Scenarios for Limiting Hypersonic Glide Vehicles,” *Journal of Strategic Studies* 42, no. 6 (September 19, 2019): 789–813, https://doi.org/10.1080/01402390.2019.1627521.

[3] On the definition of weapons and weapon platforms, see Edward Luttwak and Stuart L. Koehl, *Dictionary of Modern War* (New York: Gramercy, 1998); Eugene Gholz, “Globalization, Systems Integration, and the Future of Great Power War,” *Security Studies* 16, no. 4 (December 6, 2007): 615–36, https://doi.org/10.1080/09636410701740908.

Exclusion Rules

We exclude technologies that can be neither standalone weapons nor weapon platforms. This exclusion rule removes four types of technologies with military applications from our case universe:

1. <u>Components:</u> Our case universe excludes technologies that can only constitute a component part within larger systems. We recognize that many weapons become components when mated with a platform. Here, the term "component" refers instead to technologies that cannot be standalone weapons or platforms, such as a fuel pump in a rocket system. Components need not be ancillary widgets or insignificant innovations. The internal combustion engine, for example, is an essential component at the heart of many platforms. But we focus instead on efforts to control complete weapons or platforms—armored vehicles rather than engines.
2. <u>Enablers and Enhancers:</u> We exclude technologies that enable or enhance the performance of military capabilities. Enabling technologies, such as electricity or propulsion systems, are a special class of components that lead to major improvements in armaments. Enhancing technologies, such as stealth measures or intelligence sensors and guidance packages, augment other capabilities. We exclude these technologies as separate cases and rather consider them within the context of assessing the attributes of weapons and platforms where they have applications.
3. <u>Support and Logistics:</u> Our focus on arms excludes logistic capabilities, such as railroads, bridges, or ports, that can only perform transportation functions. Some of these platforms can be used in support roles to transport personnel and materiel, but only enter the case universe when they can also be combined with weapons to inflict damage on enemy targets—the use of specialized railcars to host artillery guns is case in point. Other support technologies, such as communication and cryptologic capabilities, play critical roles in the operation of military forces but fall outside the scope of our study. However, we do consider how these technologies shape the dual use attributes of weapons and weapon platforms. The deployment of warships and attack aircraft, for example, often relies on distinct command and control capabilities compared to their peaceful counterparts in the commercial realm.
4. <u>Production:</u> Our case universe excludes the means of production as a discrete category. But this rule does not preclude analysis of the role that such technologies play in the development process for weapons and platforms. Indeed, limits on military forces can involve curbs on the underlying capacity to produce specific weapons. Nuclear weapons, for example, rely on unique technologies to produce the exotic fissile material at the core of the explosive device. As a result, we consider production capabilities within the context of specific weapons and platforms.

One qualification is in order about how these rules apply in cases where weapons or weapon platforms use technologies that can perform other nonweapon military applications. Lasers, for example, can be used as weapons to blind human or computer targets, but are also instrumental in military communication and sensor systems. Since nonweapon applications fall outside the boundaries of our case universe, we focus on the use of laser technology as a weapon, and only consider other uses in the context of coding dual use attributes. Similarly, information technology (IT) enables an extensive range of civilian and military activities but is not itself a weapon. Our inclusion and exclusion rules lead us to focus on the specific applications of IT designed to gain unauthorized access to computer systems or to deny, degrade, or disrupt them—what many refer to as "cyber weapons." For each technology in the case universe, we make these definitional choices transparent about the specific weapon or weapon platform applications.

We exclude several other cases from the universe. Edged weapons, such as bayonets and entrenching tools, were used in wars throughout the 20th century. But we exclude this case because the technology had little impact on modern military power, so states faced few incentives to control it in the first place (including it would also bias in favor of our theory, as discussed below). Horse cavalry could also be seen as a weapons platform carrying soldiers employing weapons into battle. Beyond basic horse breeding and training practices, however, the “technology” of cavalry in the modern era primarily relied on firearms and other technological improvements in field weapons. The military use of horses as weapon platforms also reflected broader changes in tactics and military organization, not the underlying science of equitation.[4] We therefore exclude horse cavalry from the universe because it is a not a standalone weapon platform technology.

Exclusion Bias

The substantive nature of arms control as an effort to manage weapons is the primary driver behind our decision to exclude many other technologies with military applications. As we note in the paper, states may face other incentives to create international rules governing these technologies—such as optimizing international trade—but these lie beyond our scope of inquiry, which focuses instead on incentives to avoid arms races or high costs in the conduct of war. Our narrow focus on arms technology also guards against biasing the results in favor of our theory. If we were to relax the exclusion rule, then doing so would create a case universe with even stronger support for several key

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[4] In the mid-18th century, the rise of the divisional organizational structure combining different military elements—infantry, cavalry, artillery, engineers, and support—led to an increased role for cavalry in reconnaissance, screening, skirmishing, and raiding. However, the rise of what Stephen Biddle calls the “modern system” of warfare led to their demise. This increase in lethality through the volume and accuracy of fire, uses of cover and concealment, and addition of armed aircraft caused horse cavalry to become increasingly vulnerable on the battlefield. See Andrew F. Krepinevich, “Cavalry to Computer: The Pattern of Military Revolutions,” *The National Interest* No. 37 (Fall 1994): 31-34; George T. Denison, *A History of Cavalry from the Earliest Times, with Lessons for the Future, by Colonel George T. Denison*. (New York, NY: Macmillan, 1913): 281-355; Stephen Biddle, *Military Power: Explaining Victory and Defeat in Modern Battle* (Princeton, NJ: Princeton University Press, 2004).

hypotheses. A quick coding of representative technologies from each category illustrates this point:

Table A1: Excluded Technology Example Coding

Technology	Distinguishability	Integration
	Components	
Semiconductors	Low	High
Vacuum pump	Low	High
	Enablers and Enhancers	
Electricity	Low	High
Global Positioning System (GPS)	Low	High
Internal Combustion Engines	Low	High
Stealth	High	High
	Support and Logistics	
Telegraph	Low	High
Railroads	Low	High
Communication	High	High
	Production	
Industrial Manufacturing	Low	High
Additive Manufacturing	Low	High
High Performance Computers	Low	High

Most of the excluded technologies, from semiconductors to internal combustion engines, would be coded as indistinguishable and highly integrated under our variables. Since there have been no international agreements, or even serious considerations, to limit them, this larger universe of cases would seemingly lend significant support for our expectation about the dim prospects for cooperation in the dead zone (H2). Yet while the nature of technology may play some role in hindering international agreements, including these cases would likely overstate the effect of technology. In these cases, the baseline benefits from mutual restraint are low, and mutual competition can create net benefits for both sides, which creates few incentives for cooperation in the first place.

Populating the Case Universe

We applied these inclusion and exclusion rules to five existing lists of technologies to populate our case universe.

The first is a list developed by Andrew Krepinevich that captures Revolutions in Military Affairs (RMA).[5] This list was a key starting point for our technology bins, but it

[5] Andrew F. Krepinevich, “Cavalry to Computer: The Pattern of Military Revolutions,” *The National Interest*, no. 37 (1994): 30–42. For an comprehensive list of technologies based on this study, see

was also clear that major well-known technologies were missing from the RMA list. That list is both too general in some respects and focused on an evaluation of which technologies transformed warfare processes in a particular way. In our case, even technologies that are less transformative would still be relevant. Second, we evaluated several lists used for primarily economic studies. Some were clearly too fine-grained for our purpose and included the applications of technologies and subcomponents. Others, such as the Historical Cross Country Technology Adoption Dataset focus much more on civilian technologies rather than those with weapons applications which could potentially be limited via an arms control agreement.[6]

Third, we reviewed the lists of "critical technologies" that the US government has maintained over the last four decades, such as the Department of Defense (DoD)'s Militarily Critical Technologies List (MCTL) or the National Security Council's Critical and Emerging Technologies List (C&ET).[7] Although these lists provided some useful categories, they were far too inclusive of technologies beyond our focus on weapons and weapon platforms. As a GAO report recently concluded, these efforts were designed to protect "U.S. critical technologies from adversaries against illegal export, theft, espionage, and reverse engineering," but the lists tended to be "too broad to adequately guide protection."[8] Indeed, we found that the MCTL and C&ET lists identified almost every modern innovation and attendant technology that could be used to maintain US technological or military superiority. Although these lists have proved useful for scholars of export regulations and international trade, the inclusion criteria were not compatible with our definition of the relevant population set.[9]

Finally, we used full texts of every arms control agreement from 1816–2010 to create a list of all capabilities which have been limited by provisions in arms control agreements. This allowed us to confirm that capabilities limited by agreements—the positive cases—were captured by the range of technology categories we developed.

Agreement Types

Our case universe focuses attention on state efforts to manage armaments by designing arms control agreements. This scoping condition for the dataset raises the

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Jacquelyn Schneider, “The Capability/Vulnerability Paradox and Military Revolutions: Implications for Computing, Cyber, and the Onset of War,” *Journal of Strategic Studies* 42, no. 6 (September 19, 2019): 841–63, https://doi.org/10.1080/01402390.2019.1627209.

[6] Diego A. Comin and Bart Hohijn, "Cross-Country Technological Adoption: Making the Theories Face the Facts," *Journal of Monetary Economics* (January 2004): 39–83, https://www.nber.org/research/data/historical-cross-country-technology-adoption-hccta-dataset.

[7] Department of Defense, “The Militarily Critical Technologies List” (Office of the Under Secretary of Defense, Research and Engineering, 1986); National Security Council, “National Strategy for Critical and Emerging Technologies” (Washington, DC: The White House, October 2020), https://www.hsdl.org/?view&did=845571.

[8] “DoD Critical Technologies: Plans for Communicating, Assessing, and Overseeing Protection Efforts Should Be Completed” (Washington, DC: United States Government Accountability Office, January 2021), https://www.gao.gov/assets/gao-21-158.pdf.

[9] See, for example, Matthew Fuhrmann, “Exporting Mass Destruction? The Determinants of Dual-Use Trade,” *Journal of Peace Research* 45, no. 5 (September 1, 2008): 633–52, https://doi.org/10.1177/0022343308094324.

question of whether we need to further differentiate among distinct types of agreements when measuring the dependent variable. We avoid this approach for several reasons. First, scholars often try to categorize arms control agreements by types, but there is no generally accepted set of categories. Second, and more important, we eschew the choice of categorization because it can privilege certain explanatory variables. For example, dividing agreements into bilateral and multilateral categories suggests that the number of actors is a likely determinant of outcomes. To prevent such selection bias from affecting our results, we seek to explain how technology shapes constraints across all arms control agreements. But we do recognize that the magnitude of effects from technology factors may indeed vary across the values of other important variables, like relative power or the number of actors. Future research can explore whether the effects of technology-related variables are conditional on other factors.

In this study, however, it is important to acknowledge that our dependent variable groups together several types of arms control agreements that may operate via slightly different logics. For example, agreements where states agree to limit weapons in some way to gain benefits from lower risk or reduced arms spending; post-war arms controls imposed on a defeated power or other asymmetric deals where one side gains more than the other; as well as multilateral export controls designed to manage the diffusion of armaments by regulating technology transfers. Many agreements fall into the first bucket of arms limitations, which is a relatively clear set of cases to assess the degree to which variation in the features of these 'typical' arms control institutions confirms or refutes our hypotheses.

The second bucket includes a smaller subset of post-war arm control agreements. These outcomes are still arms control agreements of course, but they present additional challenges for testing our theory. The vast power asymmetry between victor and loser may be a far more significant variable in explaining outcomes, thereby making it difficult to isolate the role that technology plays even if it remains a factor.[10] It would be easy to dismiss the role of technology as a factor in this case. However, we find some evidence that it was considered as a part of the story, even if it is impossible to disentangle from the broader pressures.

In the wake of the First World War, for example, the Versailles Peace Treaty imposed strict armament control rules on Germany. After surrendering much of its military forces, Germany also had to limit "the manufacture of arms, munitions, or any war material" in industrial factories.[11] The Allied Military Committee of Versailles (AMCV) established an intrusive on-site inspection system to determine whether German factories were in compliance. Yet many of 7,000 factories in the country could produce both military and commercial goods. This created a problem. The Germans argued that they needed to retain the means of production to make reparation payments. According to the historian Richard Shuster, the AMCV instructed its inspectors "to distinguish between 'machinery for general use and machinery especially intended for the manufacture of war material,'" such as gun lathes for making artillery

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[10] See Fred Tanner, *From Versailles to Baghdad: Post-War Armament Control of Defeated States* (New York, NY: United Nations, HeinOnline, 1992).
[11] Peace Treaty of Versailles, Part V: Military, Naval and Air Clauses, Article 168, https://net.lib.byu.edu/~rdh7/wwi/versa/versa4.html.

pieces.[12] However, it proved difficult for inspectors to make this distinction in practice because many machines "could be used for both military and peaceful purposes," Shuster emphasizes. "For example, one German firm, Rhein-Metall, was able to produce artillery under the guise of railway development."[13] Much of Germany's machine tool base was left intact, which required inspectors to make repeated and surprise visits to ensure factories had not been secretly converted to military production. As a defeated nation, Germany had little choice but to accept the security risks associated with this intrusive verification regime. This type of outcome is still useful for illustrating our core mechanisms at work because it reveals how defeated powers must accept severe disclosure risks.

Finally, we consider a set of agreements that are multilateral institutions limiting the spread of certain technologies, which are often categorized as export controls regimes. The Missile Technology Control Regime or the Nuclear Suppliers Group are notable examples. These agreements are designed to prevent a third-party state, one that is not a member of the deal, form attaining a certain capability. However, to attain this mutual benefit, the members of a regime must accept a constraint on themselves and forgo the benefits that may come from unilaterally providing arms to another party, including commercial benefits for defense industries or possible security benefits from arming an ally. A violation of such a deal is not in the action of state that acquired a technology, but rather in the one that sold it. In this sense, the core logic is quite like other arms control agreements that set limits on member states.

As with the case of post-war agreements, multilateral export control regimes present some additional challenges in testing our theory. For example, they manage transfers over a wider array of dual use technologies, making it difficult to identify the specific effect of variation in dual use characteristics on agreement outcomes. The large multilateral nature of these institutions also suggests that other bargaining dynamics, such as intra-alliance issues, may play a stronger role here than in other cases.

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[12] Richard J. Shuster, *German Disarmament After World War I: The Diplomacy of International Arms Inspection 1920-1931* (London: Routledge, 2006), 65, https://doi.org/10.4324/9780203004135.
[13] Shuster, 116.

Part II: Code Book

This code book provides a four-step guide to (1) categorize technology; (2) trace its development over time; (3) specify its distinguishability and integration; and (4) identify relevant arms control outcomes of interest.

Step 1: Definitions and Boundaries

- What is the most accepted definition or scope condition for the technology?
  - Consider both scientific/engineering characteristics as well as production processes and deployment patterns.
  - Highlight the most prominent examples of this technology.
- Where are the boundaries of technology? What makes the technology distinct?
  - Specify the unique characteristics or features of the technology that make it distinct from other capabilities.
  - Indicate any areas of disagreement or confusion among analysts about categorizing the technology.
  - After completing steps 1-4, come back to steps 1 to check for bias: consider whether different categorizations of the technology might change specification of the dual use attributes.
- What kinds of specific military and/or civilian (peaceful) capabilities fall in this this category?
  - On the military side, specify whether the technology is either a weapon or weapon platform.
  - Indicate the civilian uses of the underlying technology.

Step 2: Timeline of Development

- Debut date:
  - When was the technology was first available as an operational weapon or platform?
  - Specify when actors started to adopt the technology for (A) military purposes and/or (B) civilian (peaceful) purposes.
  - Note earlier time periods where the technology was undergoing research and development or non-operational testing.
- Origins:
  - Did the technology originate in the civilian or military realms?
  - When did the technology crossover from one realm to the other? How did it diffuse?
- Where there key moments of significant innovation where the character of the technology, the way it was being developed or produced, or how it was being used in military or civilian applications?
- Are there important subsets of weapon types within the broader category?
  - For example, rifle vs. a machine gun within the firearms category, or bomb vs. a mine within explosives category.
  - Identify cases where one subset has only military applications while another has some notable civilian uses as well.

Step 3: Assessment of Technology Characteristics

Think of the technology as going through different *periods or phases*, as identified in the last section. There might be just one phase, or for older technologies you may have identified several.

Additionally, think about different the *subsets of weapon types*, and whether one weapon type or technology application is very clearly only military but another is more difficult to differentiate from more civilian applications.

For each historical phase, or notable subset of weapon type, assess the technology along two dimensions:

I. Distinguishability

A. Attribute Identification—Focus on four specific attributes to determine whether military and civilian applications of the technology had observable differences:
   1) *Physical Properties*—What were some of the properties that differentiated civilian and military applications? These can be features such as the size or observable features of the technology. Specify whether these properties differed in the civilian versus military context. Indicate whether there was a concern at the time about these properties making it difficult to distinguish between military and civilian applications.
   2) *Development Process*—What was the process of developing the technology? How much overlap or divergence was there between military and civilian development pathways? Did the technology require distinct equipment or production techniques in the military realm?
   3) *Doctrine and Deployment*—How did doctrine and/or deployment decisions for the technology impact patterns of use in the civil versus military realms? Specify the degree to which the technology was deployed for military use in ways that looked similar to civilian use. Indicate whether it was relatively difficult (in the sense of being expensive or laborious) or relatively easy to make a military capability look civilian or visa versa. If there were indeed efforts to disguise military applications as civilian, or conceal the true purpose of a certain capability, please document.
   4) *Conversion Speed*—How quickly would it take to transform the civilian version of the technology into a military asset?

B. Attribute Aggregation—Generate an overall score of distinguishability (high or low):

   First, assess the weight and relative importance of the four attributes in the context of the technology. Note whether the attributes are distinct or interrelated. Is one attribute more salient than another? Does an attribute not show up or appear to be relevant in the historical record?

   Second, aggregate the attributes into an overall measure of distinguishability. Do all attributes point in the same direction? Note any attributes that seem to cut against the grain of the overall trend.

II. Integration

A. Attribute Identification—Focus on two specific attributes to determine the relative integration of the technology:
   1) *Pervasiveness*—Specify the range and variety of uses for the technology within military enterprises and civilian sectors. Was this technology used primarily in a small set of weapons systems/platforms or was it widely used across different military capabilities? Was the technology used in a small set of civilian applications or widely used across different civilian applications?
   2) *Marginal Cost*—What was the per unit cost of development and deployment for the technology? Did the technology originate as a commercial innovation? How much "spillover potential" does the technology offer? In other words, does the technology enable or rely on other innovations or is it rather a stand-alone innovation? Are military capabilities using this technology collocated (in deployment or in production) with other military capabilities?

B. Attribute Aggregation—Generate an overall score of integration (high or low):
   First, assess the weight and relative importance of the two attributes in the context of the technology.
   Second, aggregate the attributes into an overall measure of integration. Do all attributes point in the same direction?
   Third, specify whether there are significant differences in integration for the civil versus military applications of the technology. For instance, the technology may enjoy widespread use in the military, but only offer niche applications in the civilian realm. Label such technologies as "mixed" integration cases and note the divergence (e.g. high military / low civilian).

Section 4: Outcomes

Document any effort by states to limit the military applications of the technology with formal arms control agreements.

- Where there any efforts, ideas, or discussions about international cooperation to limit the spread of this technology, certain applications of it, or access to it by different actors?
- Did anything lead to international agreements? Where there any cases where ideas were floated and rejected, even before reaching any international stage?

Security risks:

- Did states raise any concerns about the security risks associated with letting others collect information about the technology?
- Did aspects of the technology make it easier for an adversary to extract sensitive information and identify weak points in military systems? How would observing the civilian uses of the technology illuminate broader aspects of the state's broader military production base?

- Did the technology appear to increase the attack surface for sabotage? Would letting other states observe the technology further expand the menu of attack options? Could saboteurs gain better intelligence on weaknesses and additional access points to launch operations against targets?

Part III: The Dual Use Dimensions of Technology Dataset

Air Defense

Technology Definition

Air defense technology refers to the suite of technologies employed to destroy hostile missiles and aircraft.[1] Our focus on active weapon systems here excludes passive defense, deception techniques, and evasion tactics. The weapon elements of air defense are grouped into two distinct yet complementary subtypes that make this technology category unique: (1) non-terminal weapon elements, such as radar and other sensors, fire control, and communication systems, that lack the capability to inflict damage but supply critical information about the airborne target; and (2) terminal weapons that possess the capability to cause damage or "kill" the airborne target.[2] It is this combination of non-terminal (e.g., radar) and terminal (e.g., guided missile) weapon elements that makes air defense unique from other technology categories in the case universe, notably aircraft, artillery, rockets, and machine guns. The main platform and project types of terminal weapons includes guns that fire projectiles (from surface or aircraft platforms) as well as surface-to-air missiles (SAMs) and air-to-air missiles (AAMs). Our study focuses on SAMs and AAMs because these capabilities are the dominant terminal weapon in air defense, and these rockets follow a distinct flight path from ballistic and cruise missiles.[3] Air defense also includes missile defense systems, such as the Russian S-400 or the US Patriot system, since many of these capabilities can neutralize both aircraft and airborne missiles (pure missile defense systems designed only to counter ballistic missiles also fall into this category). We exclude radiation-based terminal weapon elements, such as directed energy and high energy lasers, that largely remain at an experimental and R&D stage of development. The future operationalization of these terminal systems would not significantly change our coding of the dual use attributes of air defense technology.

We define the civilian counterparts of air defense around non-terminal and terminal elements. On the non-terminal side, radar systems enjoy extensive use in the civilian realm. Given the unique and essential role that radar plays in military air defense, we focus on its dual use characteristics in peaceful applications. On the terminal side, the rocket boosters for some guided missiles can be used for civilian purposes. The most common application here is the sounding rocket, which uses a simple booster and guidance system to take measurements and perform scientific experiments during sub-orbital flight. For example, early sounding rockets used V-2 boosters for the first stage, with the instrumentation package atop a novel second stage. NASA's Sounding Rocket Program then relied on extra solid rocket motors from military air defense rockets. When

[1] For an overview of how air defense technology fits into broader military operations, see Lon O. Nordeen, *Air Warfare in the Missile Age* (Washington, DC: Smithsonian Institution Press, 1985).
[2] Jerry Michael Jones, "Air Defense Concepts and Effectiveness" (Master's Thesis, Naval Postgraduate School, 1984), 15, 19.
[3] Robert H. M. Macfadzean, *Surface-Based Air Defense System Analysis* (Boston, MA: Artech House, 1992), 135; Eugene L. Fleeman, *Tactical Missile Design*, 2nd ed., AIAA Education Series (Reston, VA: American Institute of Aeronautics and Astronautics, 2006).

the US military began phasing out the Nike Ajax SAM in the 1960s, NASA used the leftover booster motors from the decommissioned SAMs to build a cheap and highly effective sounding rocket.[4]

Time Period Boundaries

We code the debut of modern air defense around the first operational use of radar in combination with fighter aircraft by the British Royal Air Force to replace Germany's Luftwaffe air attacks during the Battle of Britain in 1940. Prior to this period, rudimentary air defenses were developed to counter the threat from early reconnaissance hot air balloons during the American Civil War.[5] Germany's introduction of airships to conduct bombing raids on England during the First World War sparked greater interest in basic air defense measures, notably via guns mounted on ground platforms and early aircraft. But the large size, slow speed, and deep vulnerability of airships made them susceptible to basic countermeasures.

Air defense technology made its operational debut when radar systems were deployed in England to aid the Royal Air Force in targeting Luftwaffe aircraft during the Battle of Britain.[6] The subsequent development of radar technology in collaboration with the Americans, combined with the growing importance of conventional bombing attacks (and the first missile attacks), led to greater investment in air defense technology.[7] During the Second World War, anti-aircraft guns were slaved to radar systems to provide more accurate aiming of the weapons. Airborne radars also increased the attack efficacy of new fighter aircraft against enemy bombers. After the war, the introduction of missiles in the terminal "kill" stage of air defense, along with more advanced radar and detection capabilities, created a period of intense development and deployment of sophisticated systems, which led to the genesis of missile defense as a key subset of this technology. Despite considerable improvements in air (and missile) defense technology from 1940 to 2020, we consider the case as a single time period because the dual use variables remained the same.

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[4] Eleanor C. Pressly, "Sounding Rockets" (Greenbelt, MD: NASA Goddard Space Flight Center, January 1965), https://ntrs.nasa.gov/citations/19650006344; William R. Corliss, "NASA Sounding Rockets, 1958-1968: A Historical Summary," The NASA Historical Report Series (Washington, DC: NASA Scientific and Technical Information Office, 1971).
[5] Kenneth P. Werrell, *Archie, Flak, AAA, and SAM: A Short Operational History of Ground-Based Air Defense* (Maxwell Air Force Base, AL: Air University Press, 1988), 1–3.
[6] John F. Kreis, *Air Warfare and Air Base Air Defense: 1914-1973* (Washington, DC: Office of Air Force History, United States Air Force, 1988), 53–92.
[7] Louis Brown, *A Radar History of World War II: Technical and Military Imperatives* (Bristol, UK: Institute of Physics Publishing, 1999); Robert Buderi, *The Invention That Changed the World: The Story of Radar from War to Peace* (London, UK: Simon & Schuster, 1996); Henry E. Guerlac, ed., *Radar in World War II* (Los Angeles, CA: American Institute of Physics, 1987).

Distinguishability: <u>High</u>

The core terminal and non-terminal technologies in air defense systems have always been highly distinguishable from their civilian counterparts (e.g., rockets and radar) for four reasons.

First, military air defense systems have several distinct physical features that set them apart from civilian capabilities. The most observable is the presence of terminal weapons in the intercept stage of the kill chain for military systems. For example, anti-aircraft artillery, AAMs, or SAMs are essential components of air defense, but civilian air radar systems lack these capabilities.[8] Guided missiles must also be optimized around specific guidance, warhead, and sensor configuration profiles to be effective in air defense. These attributes make them look different from many civilian sounding rockets, which are much simpler in design profile.[9]

Second, the terminal and non-terminal technologies in air defense must be developed to meet more intensive military requirements compared to their civilian cousins. The sensitivity and range of military radar are often much greater than civilian systems because effective air defense requires exquisite accuracy at the terminal intercept stage.[10] Air radar systems used in civilian air traffic control must be accurate and reliable, but the degree of precision needed in military air defense is much higher, which leads the development of specialized military radar systems. On the terminal side, AAMs and SAMs are also specifically designed with advanced features to defeat airborne targets.[11] By contrast, sounding rockets follow a general, low-cost development process to provide situational awareness or data collection capabilities.[12]

Third, air defense systems have unmistakable deployment features compared to civilian radar installations. Beyond the combination of terminal weapons with non-terminal technologies that are more advanced than civilian analogues, air defense systems are often deployed with other military and intelligence systems, such as command and control (C2) and early warning and cueing systems. Civilian air radar systems typically operate as standalone capabilities. The US Patriot system, for example, consists of multiple modular components, such as the fire control section (with radar, control, antenna mast, and power elements) and the SAM launchers.[13] Efforts to hide or camouflage air defense systems (including by making small, portable AAM platforms, such as the infamous Stinger missile), also indicates military use, as civilian radar installations operate out in the open. On the terminal rocket side, sounding

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[8] Kenneth P. Werrell, *Archie to SAM: A Short Operational History of Ground-Based Air Defense* (Maxwell Air Force Base, AL: Air University Press, 2005).
[9] Fleeman, *Tactical Missile Design*; Jones, "Air Defense Concepts and Effectiveness."
[10] Macfadzean, *Surface-Based Air Defense System Analysis*, 135.
[11] See, for example, Ron Westrum, *Sidewinder: Creative Missile Development at China Lake* (Annapolis, MD: Naval Institute Press, 1999).
[12] Corliss, "NASA Sounding Rockets, 1958-1968: A Historical Summary."
[13] "Patriot Fact Sheet," North Atlantic Treaty Organization, https://www.nato.int/nato_static/assets/pdf/pdf_2012_12/20121204_121204-factsheet-patriot-en.pdf.

rockets require minimum ground support equipment and facilities compared to the extensive support infrastructure required to make air defense work.[14]

Fourth, the conversion speed is generally slow from civilian radar and especially rockets to air defense. The reason is that the military mission requirements have long been extremely demanding, which makes it impractical to convert civilian products. However, some commercial innovations have been successfully leveraged to enhance the effectiveness of existing military systems. For example, the second generation of the US Aegis Ballistic Missile Defense system incorporated commercial-off-the-shelf signal processing equipment to upgrade target identification capabilities.[15]

Integration: High (Military) / High (Civilian)

On the military side, air defense systems are highly integrated because they perform a wide range of tasks across many different environments. The main goal of air defense is to provide protection for other military forces and civilian assets. For this core mission, air defense systems are often co-located with almost all types of military forces. Indeed, modern air defense strategy is explicitly premised on "integrating" these systems with many other weapon platforms and sensors to enhance overall lethality.[16] Beyond neutralizing airborne threats with terminal weapons, air defense systems also perform many other military missions, notably airspace surveillance (detecting and tracking all aircraft, drones, and other airborne objects using radar and other sensors), airspace management (controlling the movement of friendly aircraft), early warning (providing prompt situational awareness to friendly forces), and strike support (providing other strike forces, such as ground-based artillery, with information and capabilities to carry out operations).[17] One qualification is in order: air defenses are not cheap, especially those designed to counter ballistic missiles.[18] However, the pervasive nature of the technology still pushes it toward the high end of the integration spectrum.

On the civilian side, radar and sounding rockets are also highly integrated because they play many different economic and scientific roles. Radar is a versatile technology that can provide critical information, making it ubiquitous in a wide range of industries and non-military applications, including air traffic control, meteorology, navigation, wildlife conservation, agricultural monitoring, law enforcement, and border control. Commercial radar systems are also cost effective, which a wide range of

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[14] Jones, "Air Defense Concepts and Effectiveness."
[15] "Lockheed Martin's Aegis System Intercepts Ballistic Missile Target Using Satellite-Based Information for the First Time," Cision PR Newswire, February 13, 2013, https://www.prnewswire.com/news-releases/lockheed-martins-aegis-system-intercepts-ballistic-missile-target-using-satellite-based-information-for-the-first-time-191000631.html.
[16] See Jones, "Air Defense Concepts and Effectiveness"; Kreis, *Air Warfare and Air Base Air Defense*; Nordeen, *Air Warfare in the Missile Age*.
[17] For an overview of how these missions emerged in the United States, see Kenneth Schaffel, *The Emerging Shield: The Air Force and the Evolution of Continental Air Defense, 1945-1960* (Washington, DC: Office of Air Force History, United States Air Force, 1991).
[18] See, for example, Jason Sherman, "UAE Eyeing $2 Billion Purchase of Lockheed, Raytheon Patriot Missiles," *Inside Missile Defense* 23, no. 11 (2017): 1–10.

systems available on the open market for consumer and professional applications. Similarly, sounding rockets can perform a wide range of scientific and commercial tasks that involve launching instruments to altitudes between a few kilometers to a few thousand kilometers along a parabolic flight path that provides an opportunity to make measurements through the Earth's atmosphere. These launch systems are much simpler than satellites or their military missile brethren, with less elaborate launch facilities that makes them ideal for being launched "almost anywhere," as one NASA history noted.[19] Since many sounding rockets recycle old military motor components, they are also extremely cheap to use relative to space-launch vehicles, ranging from $10k to $200k each launch.[20]

Outcomes

Agreements with unilateral collection methods and/or highly restrictive inspections (managed access limits).

From 1972 to 2002, the superpowers limited a specific type of air defense technology—anti-ballistic missile (ABM) systems—in the Treaty on the Limitation of Anti-Ballistic Missile Systems. The United States and the Soviet Union signed the ABM Treaty in 1972 to limit the construction and deployment of systems designed to counter "strategic" ballistic missiles.[21] But the line between "strategic" missiles (often long range with nuclear warheads) and "tactical" or "theater" missiles (often shorter range with conventional warheads) was not defined in the treaty itself.[22] The ABM treaty limited terminal launchers and interceptors, as well as the numbers and locations of radars that were constructed and deployed for an ABM role.[23] The treaty also banned sea-, air, space-, or mobile land-based ABM systems or components.[24] But it did allow for limited ABM systems to be deployed around one national command area apiece.[25] The negotiation record reveals little concern on either side about needing additional information to differentiate ABM systems from civilian radars or sounding rockets, which aligns with our expectations for this type of distinguishable technology. Moreover, the treaty stipulated that each side would use its own intelligence capabilities ("national technical means") to verify compliance.[26] In 1989, for example, the Soviet Union admitted violation of the ABM treaty and demolished its Krasnoyarsk radar in Siberia

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[19] Corliss, "NASA Sounding Rockets, 1958-1968: A Historical Summary," 2–3.
[20] Corliss, 2.
[21] For the full treaty text, see https://2009-2017.state.gov/t/avc/trty/101888.htm#text.
[22] William J. Durch, *The ABM Treaty and Western Security* (Cambridge, MA: Ballinger Publishing Company, 1988), 44.
[23] Dennis M. Ward, "The Changing Technological Environment," in *Rockets' Red Glare: Missile Defenses and the Future of World Politics*, ed. James J. Wirtz and Jeffrey A. Larsen (Boulder, CO: Basic Books, 2001), 84.
[24] Kerry M. Kartchner, "Origins of the AMB Treaty," in *Rockets' Red Glare: Missile Defenses and the Future of World Politics*, ed. James J. Wirtz and Jeffrey A. Larsen (Boulder, CO: Basic Books, 2001), 28.
[25] Durch, *The ABM Treaty and Western Security*, 44.
[26] Durch, 45.

after the United States detected the site with unilateral methods and challenged the Soviets. The short debate over whether this radar violated the treaty had nothing to do with any ambiguity about its military nature. It was more about whether this purported early warning radar could be used in a strategic role to target ICBMs.[27] Given the highly integrated nature of air defense technology, this outcome lends strong support for H4.

In December 2001, the United States gave Russia notice of its intent to withdraw from the treaty, citing the need to defend against new threats from regional actors armed with long-range missiles and nuclear weapons. The subsequent US effort to develop homeland missile defense may have fueled arms races with both Russia and China.[28] But the eventual demise of the ABM Treaty was not related to the dual use detection or disclosure problems identified by our theory.

Beyond air defense against strategic missiles, states have only agreed to limit air defense systems in the aftermath of conflict. This could indicate that other factors are at play here, in that most air defense systems are seen as defensive and stabilizing. For several post-conflict agreements, the provisions tend to restrict inspections to special areas where numerical limits can be confirmed without exposing broader military forces to espionage. For example, the short-lived Agreement between Israel and Lebanon 1983 (also known as the May 17 Agreement) attempted to create a special security region from which Israeli military forces would withdraw.[29] Various surveillance radars and air defense guns were prohibited to remain in this geographic zone. The agreement offers neutral theory support because it quickly fell apart for reasons outside the scope of our study. In 1995, the Dayton Peace Accords also put limits on air defense radars, antiaircraft guns, and surface to air missiles/launchers as part of an agreement to curtail military forces in specific geographic zones after the Bosnian war. The agreement mandated the NATO-led Implementation Force to oversee the implementation for a fixed time period and restricted access to specific post-conflict zones and territories.[30] This outcome provides stronger support for the theory because it aligns with our expectations for H4.

Theory Support: Strong for H4. The type of agreements that emerge over strategic air defense and in the wake of conflict align with our expectations for H4. These outcomes all lend strong support for our theory because states either used unilateral means to monitor compliance, or, where inspection tools were used, states crafted highly restrictive protocols to safeguard sensitive information.

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[27] Pavel Podvig, "History and the Current Status of the Russian Early-Warning System," *Science & Global Security* 10, no. 1 (January 2002): 30–31, https://doi.org/10.1080/08929880212328.
[28] James M. Acton, "The U.S. Exit From the Anti-Ballistic Missile Treaty Has Fueled a New Arms Race," Carnegie Endowment for International Peace, December 13, 2021, https://carnegieendowment.org/2021/12/13/u.s.-exit-from-anti-ballistic-missile-treaty-has-fueled-new-arms-race-pub-85977.
[29] For the agreement text, see https://jcpa-lecape.org/wp-content/uploads/2017/10/Agreement-between-Israel-and-Lebanon.pdf.
[30] For the agreement text, see https://www.osce.org/files/f/documents/e/0/126173.pdf.

Aircraft [Fixed Wing]

Technology Definition

A fixed-wing aircraft refers to machines capable of flight that use wings to generate lift. The placement of the wings sets this type of aircraft apart from rotary-wing aircraft, such as helicopters, in which the wings are mounted on a spinning mast. We exclude gliders and kites to focus on powered airplanes that generate thrust from jet engines or propellers. Airplanes are the most common and significant class of fixed-wing aircraft. They come in many different forms and serve a variety of functions in both the military and civilian realms. Military and civilian users both draw from the same general pool of aviation technology and benefit from innovations in the broader aerospace industry. But there are major differences between most military aircraft and their civilian counterparts.

Time Period Boundaries

Fixed-wing aircraft debuted in 1903 with the first sustained airplane flight. We treat the technology as a single case study. Despite major innovations in aviation technology over the last century, fixed-wing aircraft exhibited relatively little variation in the core dual use attributes. Indeed, the technology only became increasingly distinguishable and more highly integrated within military enterprises and the civilian economy.

Aircraft [Fixed Wing], 1903–2020

Distinguishability: High

Despite using similar aviation technology, military aircraft have always been distinct from their civilian counterparts. This is particularly true for the physical characteristics of combat aircraft, which have no civilian analogue. Generally, the military and civilian realms have only used the same aircraft to fill similar logistics and transport needs. Even then, the militarized and civilian variants are typically highly modified in relation to one another.[1] The need to operate in a hostile environment led military aviation down a development path that increasingly diverged from civil aircraft over time.

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[1] Civilian passenger/cargo aircraft and military equivalents often utilize the same base airframes. A prominent example of this commonality in design is the Boeing 737 passenger airliner, which has been spun off into multiple military variants such as the C-40 cargo aircraft, P-8 Poseidon anti-submarine/surface warfare and interdiction aircraft, and the 737 Airborne Early Warning and Control aircraft. Yet these military aircraft undergo significant modifications that make them distinct from the commercial passenger aircraft. Notable exceptions to this rule are counterinsurgency aircraft, which are often militarized variants of civilian light aircraft. See Glenn E. Bugos, “The History of the Aerospace Industry,” Economic History Association, accessed on August 10, 2021, https://eh.net/encyclopedia/the-history-of-the-aerospace-industry/; Peeler, David L. 2009 “Counterinsurgency Aircraft Procurement Options: Processes, Methods, Alternatives, and Estimates.” Air Command and Staff College Wright Flyer Paper, No. 40. Maxwell Air Force Base, AL: Air University Press.

The First World War drove nations to develop combat and support aircraft capable of performing specialized missions on the battlefield.[2] These military aircraft privileged power and agility, and often built design innovations around weapons platforms. For example, machine gun synchronization gears allowed armaments to be fired safely through a propellor. By contrast, the establishment of commercial airlines and airmail routes in the 1920s led civilian aviation to favor larger aircraft with longer ranges and higher payloads. This divergence widened during the 1930s, as civilian aircraft manufacturers and operators placed a premium on comfort, safety, and operational efficiency, while the military prioritized speed and maneuverability. In this period, many innovations and production techniques developed in the civilian sector were adopted by military aircraft, including aerodynamic streamlining, retractable landing gear, improved instrumentation, pressurized cabins, and better navigational devices. Yet military and civilian aircraft were still designed in different ways to achieve fundamentally distinct operational requirements and flight characteristics.

The Second World War led to technical advances in the design and manufacture of combat aircraft. Germany developed jet-powered high-speed aircraft with swept-wing and tail surfaces to improve control. But the United States was the most successful at wartime aircraft production, as the government converted civilian industries into military mass-production hubs. However, it should be noted that this quick conversion of the aerospace sector was short lived. After the war, aviation firms came to rely on a highly skilled labor force and sophisticated manufacturing facilities as civilian and military aircraft grew more complex and expensive.

Indeed, these wartime innovations set the foundation for combat aircraft to diverge even further from civilian aviation during the Cold War, when the United States and Soviet Union competed to develop supersonic combat aircraft with unique military features, such as high-altitude reach or stealth. This arms race in military aviation technology did lead to major improvements in civilian aircraft, most notably the introduction of jet engines and computerized “fly-by-wire” systems in the 1970s that increased overall performance and efficiency for commercial airlines.[3] But military aircraft continued to exceed their civilian counterparts in terms of flight characteristics and operational capabilities, which made it increasingly easy to distinguish between the peaceful and military uses of aviation technology.[4]

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https://media.defense.gov/2017/Dec/04/2001851655/-1/-1/0/WF_0040_PEELER_COUNTERINSURGENCY_AIRCRAFT.PDF.

[2] I.B. Holley, Jr., Ideas and Weapons (1953; reis., Washington, D.C.: Government Printing Office, 1997), 29; Peter Fritzche, *A Nation of Fliers, German Aviation and the Popular Imagination* (Cambridge, Harvard University Press: 1992), 2-5; Kurt Möser, “European Aviation in the First World War,” Sorbonne Université Digital Encyclopedia of European History, accessed August 15, 2021, https://ehne.fr/en/encyclopedia/themes/material-civilization/material-modernityies-europe-in-expansion/european-aviation-in-first-world-war; Anthony L Kay, *Junkers Aircraft and Engines: 1913-1945* (London: Putnam Aeronautical Books, 2004), 12-13.

[3] NASA. “Digital Fly by Wire: Aircraft Flight Control Comes of Age.” Accessed on July 25, 2021. https://www.nasa.gov/vision/earth/improvingflight/fly_by_wire.html.

[4] The increasing costs and industrial cooperation engendered the creation of conglomerates throughout the Western World for the production of both military and civilian aircraft.

Integration: High (Military) / High (Civilian)

Fixed-wing aircraft are highly varied in design and purpose and have been utilized widely in both the civil and military spheres for well over a century. Within the civilian context, these aircraft have seen widespread use primarily for the commercial conveyance of passengers and freight, research and development, and pleasure flying. Within the military, fixed-wing aircraft are used for a full-spectrum of tasks including air-to-air combat, close air support, airborne early warning and control, and supply and logistics among other tasks.

The range and variety of uses for both military and civilian aircraft expanded during the first aviation age from 1903 to 1945. After the first viable fixed-wing aircraft capable of sustained flight was pioneered in 1903, the First World War drove government investment in aviation technology for combat purposes, resulting in more powerful and agile aircraft.[5] After the war, the civilian aviation sector adopted many of these military-led innovations to develop larger aircraft with longer ranges and higher payloads for passenger and cargo transport purposes. The emergence of airmail delivery services in the mid-1920s became a major revenue source for airlines and spurred further growth in commercial aircraft applications. As passenger air travel became more widespread in the 1930s, commercial aircraft development catalyzed a handful of major innovations to enhance efficiency, comfort, and safety. The Second World War saw significant employment of military aircraft to perform a full-spectrum of tasks including air-to-air combat, close air support, airborne early warning and control, and supply and logistics among other tasks. From a manufacturing standpoint, the war lowered production costs by introducing mass-production techniques to the aviation sector for the first time.

After the war, the aerospace sector grew into one of the largest, most economically significant, and most technically complex in the world.[6] The industry has been the target of sustained government investment because of the large capital requirements, low production runs, and high customizability. However, aviation development has broadly spurred innovation in many other research and manufacturing sectors—notably electronics and computing, telecommunications, and advanced materials—and has a great deal of technical overlap and influence upon them.[7]

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[5] I.B. Holley, Jr., Ideas and Weapons (1953; reis., Washington, D.C.: Government Printing Office, 1997), 29; Peter Fritzche, *A Nation of Fliers, German Aviation and the Popular Imagination* (Cambridge, Harvard University Press: 1992), 2-5; Kurt Möser, "European Aviation in the First World War," Sorbonne Université Digital Encyclopedia of European History, accessed August 15, 2021, https://ehne.fr/en/encyclopedia/themes/material-civilization/material-modernityies-europe-in-expansion/european-aviation-in-first-world-war; Anthony L Kay, *Junkers Aircraft and Engines: 1913-1945* (London: Putnam Aeronautical Books, 2004), 12-13.

[6] Bureau of Labor and Statistics, *Productivity in Aircraft Manufacturing,* by Alexander Kronemer and J. Edwin Hennenberger, Washington, DC, 1993, 24-26, https://www.bls.gov/mfp/mprkh93.pdf.

[7] Glenn E. Bugos, "The History of the Aerospace Industry," Economic History Association, accessed on August 10, 2021, https://eh.net/encyclopedia/the-history-of-the-aerospace-industry/.

Outcomes

Agreements with unilateral collection methods and/or highly restrictive inspections (managed access limits). Most agreements to limit conventional armaments such as combat aircraft occur in the aftermath of conflict, but restrict inspections to special areas where numerical limits can be confirmed without exposing broader military forces to espionage. The Korean War Armistice Agreement (1953), Peace Treaty between Israel and Egypt (1979), and the Florence Agreement (1996) all set various caps on how many of each type of weapon system, if any, each side is allowed to retain. However, national inspections teams can only verify numbers at 'designated ports of entry' (Korean War), certain territorial zones (Israel and Egypt), or 'export sites' (Florence). Some post-war agreements went even further with far more intrusive inspections, but only against roundly defeated nations, notably the Treaty of Versailles (1919).

There are several important agreements that also put temporal and geographic limits on inspections of aircraft technology. The most notable is the Conventional Armed Forces in Europe Treaty (1990), which included on-site inspections to verify conventional armament limitations among the signatories. Specific military aircraft—heavy bombers—are also limited under the Strategic Arms Reduction Treaty (START I, 1991) and New START (2010), both of which include inspections to verify compliance, albeit with managed access provisions.[8] For the strategic arms limitations, inspections are restricted to specific bases where a specified set of strategic aircraft are present, and changes in aircraft basing is notified to the other treaty party. These three key outcomes all lend strong support for our theory because states struggled to devise transparency measures that would reveal compliance with numerical limits on aircraft without revealing information about broader military capabilities. In each case, however, states crafted highly restrictive inspection tools and verification protocols to safeguard sensitive information.

Theory Support: Strong for H4.

[8] See Amy F. Woolf, "The New START Treaty: Central Limits and Key Provisions," Congressional Research Service Report, R41219, February 5, 2018, https://crsreports.congress.gov/product/pdf/R/R41219/54.

Aircraft [Rotary Wing]

Technology Definition

Rotary wing technology refers to aircraft with rotor blades that generate lift by rotating around a mast. We focus on the helicopter because it is the most dominant form of rotorcraft. In contrast to fixed-wing aircraft, the rotor design gives the helicopter unique flight capabilities, notably vertical take-off and landing, as well as the ability to hover and fly forward, backward, and side-to-side.

Time Period Boundaries

Rotary-wing aircraft technology made its debut when the first mass-produced helicopter became available in 1942.[1] Subsequent improvements in aviation technology, notably lightweight turboshaft engines, made helicopters widely accessible to both military users and the broader civilian market.[2] We consider the technology as a single case study because the dual use attributes exhibited little variation over time.

Aircraft [Rotary Wing], 1942–2020

Distinguishability: <u>High</u>

Despite using similar technology, military helicopters are highly distinguishable from their civilian counterparts. Many helicopters have observable physical characteristics that indicate their intended use. This is most notable for attack helicopters or 'gunships' designed to perform dedicated combat missions, such as a close air support and anti-tank operations.[3] Attack helicopters have a narrow tandem cockpit airframe to decrease their frontal target size and increase maneuverability for fast nap-of-the-earth missions, along with clearly visible sensors and external weapons.[4] Civilian utility or transport helicopters cannot be readily converted into such gunships because the recoil loads of guns, as well as the blast pressure and debris from rockets and missiles, threaten to displace or damage the aircraft in flight. In order to use the helicopter as a weapons platform, these issues must be resolved at the design stage by strengthening the

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[1] In 1942 the Sikorsky R-4 became the first helicopter to reach full-scale production. For an overview of earlier developments in rotary-wing aircraft technology, see Bill Gunston, *American Warplanes* (New York, NY: Crescent Books, 1988); Derek James, *Westland Aircraft since 1915* (London, UK: Putnam Aeronautical Books, 2003).

[2] R. D. Conner and R. E. Lee, "History of the Kaman K-225," Smithsonian National Air and Space Museum, 27 July 2001, https://web.archive.org/web/20080101194948/http://www.nasm.si.edu/research/aero/aircraft/kamen_k225.htm.

[3] Bill Gunston and Mike Spick, *Modern Fighting Helicopters* (New York, NY: Crescent Books, 1986), 10–72.

[4] Howard A. Wheeler, *Attack Helicopters: History of Rotary-Wing Combat Aircraft* (Baltimore, MD: The Nautical and Aviation Publishing Company of America, 1987), 23.

airframe to withstand blast overpressures or stabilizing the flight system to compensate for recoil.[5] Although helicopter 'gunships' are highly distinguishable, other types of modern helicopters are built around modular systems that enable the same airframe to be used for different military missions or converted into civilian use.[6] Rapid conversion speed can muddy the distinction between some types of transport helicopters that can be quickly outfitted with light weapons. Despite this overlap, the technology still looks quite different when deployed for use in hostile military versus permissive commercial environments.

Integration: <u>High</u> (Military) / <u>High</u> (Civilian)

Helicopters are highly integrated within modern militaries and within many sectors of the civilian economy. On the military side, helicopters are integral to many different land, sea, and air operations, from attacking adversaries to rescuing ground troops. Indeed, the helicopter began its military service as a support aircraft. During with the Korean War, helicopters started to be widely used for medical evacuation, reconnaissance, troop insertion, and cargo transportation.[7] The use of rudimentary gunships to provide close-air support in the Vietnam War further expanded the mission set for helicopters.[8] This led to the development of advanced attack helicopters in the early-1970s as a way to defend against an armored tank offensive attack on Western Europe from Soviet and Warsaw Pact forces.[9] The utility of attack helicopters subsequently increased as weapons platforms made major advances throughout the 1980s, notably with the introduction of sophisticated guidance systems for missiles. In addition to the anti-tank role, attack helicopters can complement fixed-wing aircraft by defeating "radar-guided antiaircraft weapons and missiles, as well as concentrations of heavily defended logistic, communication, and command centers, and troop concentrations."[10] On the civilian side, helicopters perform a wide range of indispensable functions for many different industries and users. The most prominent use of helicopters is to transport cargo and passengers, especially in locations where fixed-wing aircraft cannot takeoff or land due to the absence of a runway. Helicopters also perform a variety of surveillance and data collection operations, such as reporting on traffic conditions, police patrol work, water usage, and oil and gas exploration.[11]

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[5] E. J. Everett-Heath et al., *Military Helicopters* (London, UK: Brassey's, 1990), 78–79.
[6] For example, the AgustaWestland AW101 can be reconfigured from military transport to anti-submarine warfare (ASW) in hours; it can also be modified for civil operators to transport high-value passengers. For an overview, see James, *Westland Aircraft since 1915*.
[7] Wheeler, *Attack Helicopters*, ii.
[8] Everett-Heath et al., *Military Helicopters*, 77; Wheeler, *Attack Helicopters*, 57–70.
[9] Gunston and Spick, *Modern Fighting Helicopters*, 195–96.
[10] Andy Lightbody and Joe Poyer, *The Illustrated History of Helicopters* (Lincolnwood, IL: Publications International, 1990), 18.Lightbody 18
[11] Lightbody and Poyer, 6.

Outcomes

<u>Agreements with national technical means and/or highly restrictive inspections (managed access limits)</u>. See the outcomes detailed in the Aircraft [Fixed-Wing] case above, as almost every agreement to limit conventional military forces and fixed-wing aircraft also includes caps on rotary-wing attack helicopters, especially the Conventional Forces in Europe treaty (the main exceptions are the START and New START agreements that focus on strategic, nuclear-capable combat aircraft).

Theory Support: <u>Strong for H4</u>.

Airship [Dirigible]

Technology Definition

An airship refers to a dirigible balloon or lighter-than-air (LTA) aircraft that gains lift from filling itself with gas (usually hydrogen or helium) that is less dense than the surrounding air. The size of the airship determines its lift capabilities: the greater the volume of gas inflating the hull, the heavier the load it can carry.[1] This feature separates airship technology from aircraft that use wings (fixed or rotary) to generate lift, such as airplanes and helicopters. In the past, the ability to generate static lift without use of engine power was the key advantage of airships, especially before the advent of more efficient jet engines for modern aircraft. This feature enabled airships to perform long-duration and long-range missions. Engines were attached to airships for lateral thrust and maneuverability. However, the use of gas as the lifting agent required very large balloons or rigid and semi-rigid hulls, which decreased speed and mobility.[2] Airships have been used as weapon platforms to deliver bombs and other munitions against targets. But this role was rendered obsolete by advances in modern aircraft technology [see the Aircraft case studies]. However, airships and especially high-altitude balloons remain used in select nonweapon military applications such as intelligence collection and communications. Airships also enjoy an extensive range of applications in the civilian sector, from weather balloons to various scientific experiments and commercial data platforms.[3]

Time Period Boundaries

We code the debut of airships in July 1900 with the first flight of the Luftschiff Zeppelin *LZ1,* which led to the introduction of the highly effective Zeppelin line of airships in the early 20th-century. Airships were first used as weapon platforms for rudimentary bombing missions during the Italo–Turkish War in 1912.[4] The main belligerents in World War I employed airships as bombing, attack, and observation platforms. During the interwar period, airships provided commercial cargo and passenger services until Hindenburg disaster of 1937 dampened public demand for the technology relative to airplanes. It is important to note that airships had become obsolete for most bombing and attack missions by the onset of World War II. The main exceptions were the use of airships in anti-submarine warfare (ASW) and rudimentary air defense during the war, as discussed below. In the postwar era, airship technology was used in a wider range of civilian functions (e.g., the Goodyear blimp in commercial settings or weather balloons). The US military used the technology as a surveillance platform in Afghanistan but

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[1] See Guy Hartcup, *The Achievement of the Airship: A History of the Development of Rigid, Semi-Rigid, and Non-Rigid Airships* (London, UK: David & Charles, 1974), 20.
[2] On this tradeoff, see G. A. Khoury and J. D. Gillett, eds., *Airship Technology* (New York, NY: Cambridge University Press, 1999).
[3] See William J. Broad, "A Rising Awareness That Balloons Are Everywhere in Our Skies," *The New York Times*, February 14, 2023, sec. Science, https://www.nytimes.com/2023/02/14/science/weather-balloons-stratosphere.html.
[4] Hartcup, *The Achievement of the Airship*, 46.

phased out the use of rigid airships by 2017 (although smaller reconnaissance balloons remained operational).[5] The periodic revival of the technology for specific military purposes leads us to examine the dual use attributes from its debut in 1900 until the endpoint of our dataset in 2020.

Airship [Dirigible], 1900–2020

Distinguishability: <u>High</u>

Airships are highly distinguishable for four reasons. First, the large physical characteristics of airships readily revealed distinct differences between military and civilian platforms. Airships all share similar hull designs. But the "gondolas" or "cars" hung beneath the hull were built to perform specific military or commercial functions.[6] For example, the civilian version of the Zeppelin airships contained a gondola with crew quarters in the front and a luxury passenger compartment midway between the engine compartment. Entirely new gondolas had to be built for military purposes around observable bomb bays and hard points for light attack weapons and other sensors.[7] One notable example was the *K-class* blimp built by the Goodyear Aircraft Company for American military operations against German U-boats during World War II. As one military historian recounts, the "K-ships" for the US Navy had multiple distinctive features:

> each airship was provided with an ASG-type radar unit capable of detecting objects at 90 miles. Underwater search equipment included sonobuoys and MAD gear. Armament for the K-ship normally included four torpex filled Mk 47 (350-pound) depth bombs, two on external bomb racks and two in the bomb bay. A 50-cal. Browning aircraft machine gun was placed in a turret in the forward part of the K-ship's control car. For fire power from the after end of the car, many K-ships had Browning automatic rifles available for installation in the aft windows which were removable. The 40 foot-long control car carried the crew, armament, power plants and most of the equipment.[8]

These features were all highly observable, making military airships distinguishable from peaceful blimps.

Second, the development pathways for military and commercial airships often diverged during wartime to meet specific force requirements. At the onset of WWI, for example, Germany launched a concerted effort to build new airships for reconnaissance

[5] Graham Bowley, "Spy Balloons Become Part of the Afghanistan Landscape, Stirring Unease," *The New York Times*, May 12, 2012, sec. World, https://www.nytimes.com/2012/05/13/world/asia/in-afghanistan-spy-balloons-now-part-of-landscape.html.
[6] Douglas Botting, *The Giant Airships* (Alexandria, VA: Time-Life, 1981).
[7] Hartcup, *The Achievement of the Airship*, 62–128.
[8] Roy A. Grossnick, *Kite Balloons to Airships: The Navy's Lighter-than-Air Experience* (Washington, DC: Government Printing Office, 1986), 36.

and strategic bombing missions.[9] The existing fleet of civilian airships were not able to accomplish these tasks. With German state support, the Zeppelin Company increased the capacity of its airships to carry heavier loads, especially multi-ton bombs. Machine-guns and special observation equipment were also mounted on platforms around the hull and in the fore and aft gondola car of these P-class airships.[10] In an attempt to overcome rapidly evolving air defenses, "the Germans then built airships in which comfort, safety and even speed were sacrificed to the capacity to reach altitudes of 20,000 feet and more," one historian noted.[11] To save weight, the crew's quarters were eliminated and the control car was made smaller. The undersides of the new attack ships were painted black to dampen reflection from ground-based searchlights.[12] These requirements stood in stark contrast to the development of civilian airships. During the interwar period, for example, airships remained remarkably prone to accident, and therefore had to undergo extensive modifications for safety and reliability before they could prove viable in civilian transportation.[13]

Third, the deployment patterns for military airships also differed from their civilian counterparts. During bombing raids in WWI, for instance, German airships would evade British air defenses by lurking above or inside dense clouds—an inherently unsafe operation that civilian airships were keen to avoid. A small observation basket would then be lowered at the end of a cable until it broke through the cloud base, where it could guide the main airship toward a ground target.[14] This method of deployment had no civilian analogue. Similarly, in WWII, the United States formed airship bases around coastal areas and shipping lanes because the US Navy deployed airships for convoy escort work and submarine hunting in small patrol squadrons.[15]

Fourth, the speed of converting commercial into military airships remained relatively slow. As noted above, the Germans invested heavily in developing entirely new classes of heavy lift and high-altitude airships during WWI because their existing fleet of commercial airships could not be converted into effective weapon platforms. In WWII, the Americans also commissioned military airships with tailored specifications from the Goodyear Company rather than convert civilian blimps. However, many of these military platforms were converted into commercial airships in peacetime.[16]

Recent attention on high-altitude balloons raises the question of whether airships without clear weapon platform features are also highly distinguishable.[17] Although smaller military balloons have proven difficult to distinguish from civilian platforms on radar, the visible equipment hanging below the balloon often indicates end use in much the same way as earlier generations of weaponized airships. In February 2023, for example, US surveillance planes took images of a Chinese balloon to determine its

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[9] Botting, *The Giant Airships*, 51.
[10] Hartcup, *The Achievement of the Airship*, 94–95.
[11] Basil Collier, *The Airship: A History* (New York, NY: Putnam, 1974), 10.
[12] Botting, *The Giant Airships*, 65–66.
[13] Hartcup, *The Achievement of the Airship*, 143.
[14] Joseph F. Hood, *When Monsters Roamed the Skies: The Saga of the Dirigible Airship*, Adventures in Flight (New York, NY: Grosset & Dunlap, 1968), 31.
[15] Hartcup, *The Achievement of the Airship*, 247.
[16] See Grossnick, *Kite Balloons to Airships: The Navy's Lighter-than-Air Experience*.
[17] Broad, "A Rising Awareness That Balloons Are Everywhere in Our Skies."

military intelligence or civilian research use. According to the State Department, the equipment and antennas on the balloon indicated it “was clearly for intelligence surveillance and inconsistent with the equipment on board weather balloons.”[18] As a result, balloons appear to be distinguishable upon visual inspection. But this use case should be watched to determine if airships become more integrated as intelligence platforms in the years ahead.

Integration: Low (Military) / High (Civilian)

Airships represent a unique case of low military but high civilian integration because many of the weapon applications for the technology became obsolete by the 1950s, leaving only intelligence missions. By contrast, airships continued to offer a wide range civilian applications at low cost, even after the Hindenburg disaster dampened demand for transportation. We therefore consider the technology to fall within the “disclosure constraint” zone.

Airship technology made its debut in the early-20th century with great promise of fulfilling a variety of commercial and then military roles. However, airships were soon relegated to a narrow range of military missions during WWI, notably strategic bombing against civilian targets. In the summer of 1915, the Germans launched their first bombing raids on the city of London with airships. This initial campaign caused modest damage and loss of life but did invoke considerable psychological fear about this new method of attack.[19] As anti-airship defenses improved, German Zeppelin airships found it increasingly difficult to attack either France or Britain.[20] This led to the development of new airships that could fly at higher altitudes to evade air defense. Improvements to the Zeppelins enabled bombing raids against England to recommence in the fall of 1916, but this effort was so unsuccessful it called into question the military utility of airships as weapon platforms. The airships were easily hindered by poor weather and still venerable to air defenses; they also lacked the carrying capacity or precision necessary to inflict serious damage against ground targets.[21] As the airships moved to higher altitudes to avoid air defenses, they also became less effective at supporting naval operations because “they could see neither submarines nor mines, or even correctly identify large ships.”[22] The German military determined that the effort required to construct the airships outweighed the material damage they inflicted from the bombing runs.[23] Indeed, construction of each airship was quite expensive; operational airships also required extensive support infrastructure.[24] Similarly, British airships, which were several generations behind the German Zeppelins, also "achieved virtually nothing"

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[18] Edward Wong and Julian E. Barnes, “Chinese Balloon Had Tools to Collect Electronic Communications, U.S. Says,” *The New York Times*, February 9, 2023, sec. U.S., https://www.nytimes.com/2023/02/09/us/politics/china-spy-balloon-program.html.
[19] Collier, *The Airship*, 80.
[20] Hartcup, *The Achievement of the Airship*, 96.
[21] Hartcup, 99.
[22] Botting, *The Giant Airships*, 69.
[23] Botting, 73.
[24] Hartcup, *The Achievement of the Airship*, 104.

during the war.[25] The use of airships as bombing platforms was rendered obsolete as fixed-wing aircraft became increasingly capable by the end of the war.

During World War II, the US Navy revived airship technology, but primarily to perform anti-submarine duties. Large uncrewed tethered barrage balloons were also used to defend against aircraft attack at low altitudes (the British even employed barrage balloons to stop over two-hundred V-1 attacks). Extensive use of airships to patrol coastal waters and escort shipping convoys in the North Atlantic belied the limited mission set for the technology.[26] Most of these airships were decommissioned. After the Korean War, the United States briefly considered maintaining squadrons of next-generation airships specifically designed for ASW that could carry torpedoes and depth charges, and "equipped with radio, radar, MAD gear, sonar, a searchlight, and facilities for in-flight refueling at sea from surface ships."[27] But routine patrols with the airships ended in 1961, with more capable rotary-wing aircraft subsuming similar functions in ASW operations.[28] The most recent return of airships by the US military in Afghanistan for overhead reconnaissance followed a similar pattern as new technologies, notably aerial drones and low earth orbit satellites, offered better options. However, airships remain viable platforms for intelligence collection and observation—a point vividly illustrated in February 2023 when a Chinese high-altitude balloon traversed the continental United States before being shot down over the Atlantic Ocean.[29] Despite recurrent discussions about rearming airships, intelligence and communication missions are the only military application left for the technology.[30]

The level of integration within the civilian economy remained high even after key transportation applications were abandoned in the 1940s. The development of heavy lift and long-distance airships during WWI opened opportunities for commercial cargo and passenger services. Yet safety concerns in the aftermath of the 1937 Hindenburg disaster doomed public demand for civil airship flights relative to fixed-wing aircraft.[31] In contrast to their military brethren, however, commercial airships remain useful in many different applications where the need to hover for an extended duration is greater than speed and maneuverability requirements, most notably advertising, aerial observation (e.g., the Goodyear blimp), meteorology (e.g., weather balloons), data transmission, and agriculture.[32] As a producer of high-altitude balloons underscored in 2023, the array

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[25] Hartcup, 110.
[26] Hood, *When Monsters Roamed the Skies: The Saga of the Dirigible Airship*, 129.
[27] Hartcup, *The Achievement of the Airship*, 249.
[28] Collier, *The Airship*, 223.
[29] Helene Cooper and Edward Wong, "Downing of Chinese Spy Balloon Ends Chapter in a Diplomatic Crisis," *The New York Times*, February 4, 2023, sec. U.S., https://www.nytimes.com/2023/02/04/us/politics/chinese-spy-balloon-shot-down.html.
[30] See Edward B. Tomme, "The Paradigm Shift to Effects-Based Space: Near-Space as a Combat Space Effects Enable," Research Paper, Air University, Maxwell Air Force Base, AL, 2005, https://apps.dtic.mil/sti/pdfs/ADA434352.pdf; Kevin B. Massie, "Bombs From On-High: Weaponized Stratospheric Airships for Close Air Support and Time-Sensitive-Target Missions," Research Report, Air University, Maxwell Air Force Base, AL, April 2009, https://apps.dtic.mil/sti/pdfs/ADA539680.pdf.
[31] Hartcup, *The Achievement of the Airship*, 199–230.
[32] See for example the data transmission architecture that Google developed around airships with Project Loon: Steven Levy, "How Google Will Use High-Flying Balloons to Deliver Internet to the Hinterlands," *Wired*, June 14, 2013, https://www.wired.com/2013/06/google-internet-balloons/.

of different civilian balloons and nonmilitary programs is “endless.”[33] These systems are also relatively low cost, especially compared to other aerospace technologies.[34]

Outcomes

Agreement imposed on defeated power. In the wake of the First-World War, the Versailles Peace Treaty imposed strict armament control rules on Germany.[35] This outcome lends neutral support for our expectations about H4 because the role of technology is difficult to isolate in this case where post-war armament controls were imposed on defeated nation. The Treaty of Versailles imposed intrusive inspections to verify controls and bans over many military technologies—Germany had little choice but to accept these provisions. After surrendering much of its military forces, Germany was prohibited from keeping air force capabilities, including dirigibles and airships (see Article 198). In addition, the treaty forbid “the manufacture and importation of aircraft, parts of aircraft, engines for aircraft, and parts of engines for aircraft,” notably dirigibles and their underlying support and production capabilities (see Articles 201 and 202). The Allied Military Committee of Versailles (AMCV) established an intrusive on-site inspection system to determine German compliance, along with a special Aeronautical Inter-Allied Commission of Control to deal with airship controls. Article 210 made these inspection provisions explicit:

> In particular it will be its [the Aeronautical Inter-Allied Commission of Control] duty to make an inventory of the aeronautical material existing in German territory, to inspect aeroplane, balloon and motor manufactories, and factories producing arms, munitions and explosives capable of being used by aircraft, to visit all aerodromes, sheds, landing grounds, parks and depots, to authorise, where necessary, a removal of material and to take delivery of such material.
>
> The German Government must furnish to the Aeronautical Inter-Allied Commission of Control all such information and legislative, administrative or other documents which the Commission may consider necessary to ensure the complete execution of the air clauses, and in particular a list of the personnel belonging to all the German Air Services, and of the existing material, as well as of that in process of manufacture or on order, and a list of all establishments working for aviation, of their positions, and of all sheds and landing grounds.

In the years after Versailles, it becomes difficult to fully test the theory with this case because the obsolescence of airships as a weapons platform created the situation where there was nothing to limit. If they were still in use as weapons (not just intelligence collection platforms), our theory would predict that the technology would not create constraints.

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[33] Broad, “A Rising Awareness That Balloons Are Everywhere in Our Skies.”
[34] Khoury and Gillett, *Airship Technology*.
[35] For the full text, see Peace Treaty of Versailles, https://net.lib.byu.edu/~rdh7/wwi/versa/versa4.html.

Theory Support: Neutral for H4. We consider the technology to fall within the "disclosure constraint" zone because of the high level of civilian integration, but it could also be included in the "permissive zone" with little impact on theory evaluation due to the neutral support.

Armored Vehicles

Technology Definition

Armored vehicle technology refers to a family of ground vehicles that are driven by an internal-combustion engine and fitted with protective armor. Many armored vehicles are also equipped with weapon systems, such as turreted cannons on battle tanks or light-machine guns on personnel carriers. The technology made its battlefield debut in 1914, when the British Army combined three recent innovations into a single vehicle system: (1) the power-drive of the internal combustion engine; (2) the lethality of large-caliber high-velocity guns and artillery; as well as (3) the maneuverability of continuous caterpillar tracks to traverse off road. Early battle tanks were fitted with heavy armor to protect the crew and weapon system from damage as they attempted to break the stalemate of trench warfare during the First World War.[1] Subsequent improvements made armored vehicles more lethal, maneuverable, and survivable.[2] As a result, the technology is used almost exclusively for military or state security purposes. The sole exception is the use of armored cars to transport high-value assets between safe locations. We exclude tractors and heavy track machines because we see this as a class of technology that is fundamentally different from armored vehicles. However, a broader definition could potentially include heavy track machines, such as earth excavators used extensively throughout the civilian economy. Using the broader definition would not significantly alter coding as distinguishability and integration of heavy track machines would still be high (but it would make the technology more highly integrated within the civilian economy).

Time Period Boundaries

We code the debut of armored vehicle technology around its first deployment in 1914. Given the stable nature of the dual use attributes, we treat armored vehicles as a single case study over time.

Armored Vehicles, 1914–2020

Distinguishability: <u>High</u>

An armored vehicle is primarily a military technology. There are some civilian analogues available for high-value transport missions. But this peaceful application has always been highly distinguishable from the broader military uses for three reasons.

First, the physical characteristics of military armored vehicles set them apart from their civil counterparts and related heavy vehicle technology (such as commercial tractors with caterpillar tracks). The most obvious feature is the inclusion of identifiable

[1] Michael Foley, *Rise of the Tank: Armoured Vehicles and Their Use in the First World War* (Barnsley, UK: Pen and Sword Military, 2014).
[2] Richard M. Ogorkiewicz, *Design and Development of Fighting Vehicles* (London, UK: Doubleday, 1968).

weapon systems on many armored vehicles, such as the long gun on a battle tank. Even vehicles without weapons, such as some personnel carriers or mobile command centers, need to be better protected and armored to survive in a hostile military environment.[3] Second, military and civilian armored vehicles follow radically different development paths. On the military side, the vehicles are designed suis generis to maximize different combinations of lethality, protection, and maneuverability. For example, the tank is built around its main gun, which needs a stabilization system and crew safety measures to perform on the battlefield. By contrast, civilian armored cars just modify a standard commercial van or truck chassis, adding bullet-resistant glass and light armor plating (which makes them closer to motor vehicle technology). Third, the deployment of armored vehicles for military purposes is distinct from civilian high-value asset protection. Tanks are typically employed alongside infantry and artillery to rapidly seize terrain, while lighter armored personnel carriers carry soldiers into battle.[4]

Integration: <u>High</u> (Military) / <u>Low</u> (Civilian)

Armored vehicles exhibit different integration scores within the military versus civilian spheres. On the civilian side, armored cars play an important but limited role in keeping valuable assets safe during transport. These vehicles are more expensive than typical unarmored automobiles and have no spillover potential into other sectors beyond narrow civil security applications. By contrast, armored vehicles are highly integrated into modern militaries. The technology is widely used across different military capabilities to perform four main missions: (1) attacking adversarial forces and seizing terrain with an extensive range of vehicular weapons, from tank guns and anti-tank missiles to mounted machine guns; (2) protecting troops and material while moving them into battle; (3) conducting reconnaissance; and (4) providing support to other fighting elements (e.g. self-propelled artillery or medical evacuation).[5] Each mission set privileges vehicles with varying degrees of lethality, survivability, and maneuverability. This tends to drive development patterns in the technology over time, as advances in armor or munitions often lead to countervailing improvements in protection or destructive power. Armored vehicles also rarely fight on their own—they are designed to enhance the battlefield effectiveness of other forces. During the Second World War, for instance, the German army pioneered the use of battle tanks to quickly seize territory with the infantry and artillery in support of armored warfare maneuvers. The marginal cost of producing armored vehicles for military use is certainly higher in comparison to their civilian counterparts, especially standard motor vehicles equipped with basic armor. Whereas an armored cash transport car ranges from $50–500k per unit, battle tanks and infantry fighting vehicles are far more expensive (the M1 Abrams is

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[3] Ian V. Hogg, *Armour in Conflict: Design and Tactics of Armoured Fighting Vehicles* (London, UK: Jane's Information Group, 1980).
[4] Richard E. Simpkin, *Human Factors in Mechanized Warfare* (Oxford, UK: Pergamon Press, 1983).
[5] Duncan Crow and Robert J. Icks, *Encyclopedia of Tanks* (Secaucus, NJ: Chartwell Books, 1975).

$9mil/unit) and require costly maintenance and logistical support.[6] In the context of military expenditures, however, armored vehicles involve quite modest production costs, which makes it easy to integrate the technology into a wide range of military operations.

Outcomes

Agreements with unilateral collection methods and/or highly restrictive inspections (managed access limits). Most agreements to limit conventional armaments such as armored vehicles occur in the aftermath of conflict, but restrict inspections to special areas where numerical limits can be confirmed without exposing broader military forces to espionage. The Korean War Armistice Agreement (1953), First Indochina War Demilitarized Zone Geneva Conference (1954); Peace Treaty between Israel and Egypt (1979), and the Florence Agreement (1996) all set various caps on how many of each type of weapon system, if any, each side is allowed to retain. However, national inspections teams can only verify numbers at 'designated ports of entry' (Korean War), certain territorial zones (Israel and Egypt), or 'export sites' (Florence). Some post-war agreements went even further with far more intrusive inspections, but only against roundly defeated nations, notably the Treaty of Versailles (1919).

The Conventional Armed Forces in Europe Treaty (1990) includes on-site inspections to verify conventional armament limitations among the signatories, including armored vehicles. But CFE puts temporal and geographic limits on these inspections. Other agreements limit the export of armored vehicles to conflict zones, such the Nairobi Protocol and the ECOWAS Convention—these efforts established mechanisms for better information sharing among member states. There are also several regional confidence building measures (e.g., India-China) that establish rules on how states can deploy armored vehicles near specific territorial borders. But these agreements just require states to provide advance notification about military force movements—no additional verification measures are in place. These outcomes all lend strong support for our theory because states either used unilateral means to monitor compliance, or, where inspection tools were used, states crafted highly restrictive protocols to safeguard sensitive information.

Theory Support: Strong for H4.

[6] U.S. General Accounting Office, "Ambrams Tank: Operating Costs More Than Expected," Report to the Chairman, Committee on Armed Services, House of Representatives, February 1991, https://www.gao.gov/assets/nsiad-91-114.pdf; Congressional Budget Office, "Projected Acquisition Costs for the Army's Ground Combat Vehicles," April 2021, https://www.cbo.gov/system/files/2021-03/57085-ground-combat-vehicles.pdf.

Artillery

Technology Definition

The term 'artillery' denotes cannons (such as howitzers, mortars, and recoilless rifles) that are capable of quick indirect fire over long distances, often directed at targets by distant observers. Despite its intrinsic military nature, artillery is also used in select civilian applications, most notably avalanche management to clear dangerous snowpack above transportation routes and towns.

Time Period Boundaries

Although various artillery pieces have been employed in warfare since antiquity, modern cannon technology made its debut as a new type of weapon system at the end of the 19th century for two reasons. First, innovations in rifling, explosives, and metallurgy during the Industrial Revolution set the foundation to build larger steel artillery pieces capable of firing more powerful ordnance compared to previous generations of bronze and iron field guns. The development of a recoil management system in 1897 is often considered to mark the birth of modern artillery, as this invention allowed the new weapons to increase their rate of fire while maintaining accuracy.[1] Second, modern artillery was designed to provide long-range indirect fire, whereby forward deployed or 'distant' observers would communicate with artillery officers far removed from the actual target. Advances in communications technology made indirect fire tactics possible, starting with the first use of the telephone on the battlefield in 1900 to relay targeting information from field commanders.[2]

Artillery systems with these twin features debuted on the battlefield in the 1899–1902 Second Anglo-Boer War, the 1904–1905 Russo-Japanese War, and the Balkan Wars of 1912–1913.[3] The main belligerents of the First World War pioneered various artillery capabilities and operational doctrines, pushing forward the development of new high-explosive compounds to create more destructive and lethal projectile shells.[4] Indirect fire tactics allowed artillery to remain in concealed positions behind defilade, which dramatically increased the firing unit survivability. Artillery soon became an essential means of providing ground forces with general fire support. The technology made incremental advancements after its main debut, especially amid the development of precision-guided munitions in the late-20th century. But artillery tactics remained rooted in the notion of indirect fire support for other military forces.

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[1] Jeff Kinard and Spencer C. Tucker, *Artillery: An Illustrated History of Its Impact*, Weapons and Warfare (Oxford, UK: ABC-CLIO, 2007); Martin Van Creveld, *Technology and War: From 2000 B.C. to the Present*, Revised&Expan edition (New York, NY: The Free Press, 1989), 170.
[2] Creveld, *Technology and War*, 174.
[3] Kinard and Tucker, *Artillery*, 232.
[4] Mark E. Grotelueschen, *Doctrine Under Trial: American Artillery Employment in World War I* (Westport, CN: Praeger, 2000).

Distinguishability: High

Artillery comes close to being a pure military technology. However, the same weapon platforms can be installed to perform peaceful applications in the civilian context of avalanche control. This is a niche role for the weapon, but one that generates significant economic and safety benefits in many mountainous regions throughout the world. Although a variety of non-artillery systems exist to clear avalanches, military cannons offer a unique capability. According to the US Forest Service, "[artillery] alone allows avalanche control workers to fire rounds from a single fixed accessible location and trigger avalanches in distant inaccessible starting zones. Other remote delivery systems are typically less accurate, have less range, and deliver less explosive power than military artillery."[5] Although civilians use the exact same artillery pieces as their military counterparts, the distinguishability of the technology is quite high for three reasons.

First, the deployment pattern for artillery looks different in the military versus civilian context. In contrast to large and often highly mobile military artillery units, peaceful avalanche control stations install a single artillery gun at a fixed location behind special protective barriers designed to shield the operators from accidental explosive blasts. After several accidents in the United States, for example, the US Forest Service prohibited mobile artillery and required that all avalanche control firing be performed from fixed locations with protective barriers.[6] Civilian operators also have a limited supply of ordnance, and keep detailed records of all avalanche firings to ensure that duds can be located and destroyed. Moreover, geography indicates intended use, as there must be a consistent risk of avalanche danger to warrant the installation and operation costs associated with artillery.

Second, converting civilian artillery guns into militarily useful platforms is difficult and costly because deploying small numbers of artillery in remote mountain areas does not set the foundation to gain a sudden military advantage. It would be impractical to use avalanche control as cover to buildup military artillery. Isolated avalanche control stations are not suited to perform military missions. The speed of conversion would be slow. The firing stations would need to be modified and the logistical support system

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[5] Doug Abromeit, “United States Military Artillery for Avalanche Control Program: A Brief History in Time,” *Proceedings of the 2004 International Snow Science Workshop*, 2004, 611–19, https://arc.lib.montana.edu/snow-science/objects/issw-2004-611-619.pdf.

[6] The US Army Tenth Mountain Division made extensive use of artillery to clear avalanches during the Second World War, and then brought this method back to the United States. In 1949, the US Forest Service arranged for the National Guard to install an old 75mm French Howitzer for avalanche control. Following the success of this experiment, the Forest Service Snow Rangers began using several other types of military artillery, eventually settling on vintage recoilless rifles. These weapons were designed to be mobile and shot from vehicles such as Jeeps. At first, the Forest Service deployed recoilless rifles in a similar fashion, firing them from the back of pickup trucks. After several accidents, however, the Forest Service prohibited mobile mounts and required that all avalanche control firing be performed from fixed locations with protective barriers. This made the use of artillery for avalanche control look quite distinct from military deployment on the battlefield, which accepted greater risks of accidents and relied upon far greater logistical support infrastructure to improve mobility and lethality. See Abromeit.

would need to undergo a major expansion to enable mobility and provide large amounts of ammunition.

Third, the artillery technology used in advanced militaries has steadily diverged from the vintage weapons and ordnance used for avalanche control. In the United States, for instance, the Forest Service and private firms rely on old surplus artillery pieces (e.g., 75mm French Howitzers in the 1950s or 105mm Howitzers today) and ammunition. While these systems perform well at triggering avalanches, they have become increasingly obsolete in the modern military context. Starting in the 1970s, the US military transitioned to sophisticated artillery systems and expensive ordnance (especially precision-guided munitions). Although surplus artillery could certainly be recalled for military purposes, the use of these antiquated systems in the civilian context sets them apart from their more advanced military descendants.

Integration: High (Military) / Low (Civilian)

Cannons and siege weapons have long been a highly integrated military technology, used in a wide variety of combat roles to support ground forces over the millennia. Modern artillery systems with indirect fire and distant observer capabilities are no exception, playing a key role in conventional military operations.[7] The general role for artillery is to provide fire support in coordination with other forces to destroy, neutralize, or suppress targets.[8] Within these parameters, the range and variety of specific tasks assigned to artillery is extensive, from area suppression and point target destruction to combined arms plans of attack. Beyond the widespread use of artillery in the military, the marginal cost of development and use is low. Conventional munitions are cheap, ranging from $100–1000 per round (from vintage to more modern cannon systems). More advanced artillery systems, such as the M777, support more expensive guided munitions. These precision-strike shells range from $10,000 per round to equip old conventional munitions with guidance packages to $100,000 per round to manufacture ultra-precise satellite-guided artillery shells from scratch.[9] Finally, modern artillery systems are highly connected by innovation in other technology areas. Advances in material science, control systems, and precision guidance have all improved artillery system capabilities. By contrast, the range and variety of uses for civilian artillery is limited to avalanche control. Although artillery provide significant economic and safety benefits by allowing major transportation routes to remain open during winter, this niche application indicates a low level of integration on the civilian side.

Outcomes

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[7] David T. Zabecki, *Steel Wind: Colonel Georg Bruchmüller and the Birth of Modern Artillery*, The Military Profession (Westport, CN: Praeger, 1994).
[8] Maj Gen J. B. A. Bailey, *Field Artillery and Firepower* (Annapolis, MD: Naval Institute Press, 2003).
[9] Mike Hanlon, “The Cannon of the 21st Century - the Howitzer M777,” New Atlas, December 5, 2005, https://newatlas.com/the-cannon-of-the-21st-century-the-howitzer-m777/4903/; Joe Gould, “US Army ‘Dumb’ 155mm Rounds Get Smart,” Defense News, March 13, 2015, https://www.defensenews.com/land/2015/03/13/us-army-dumb-155mm-rounds-get-smart/.

Agreements with unilateral collection methods and/or highly restrictive inspections (managed access limits). Most agreements to limit conventional armaments such as artillery occur in the aftermath of conflict, but restrict inspections to special areas where numerical limits can be confirmed without exposing broader military forces to espionage. Some ceasefire agreements, such as the Israel-Egypt Armistice Agreement (1949), Peace Treaty between Israel and Egypt (1979), and the Florence Agreement (1996) all set various caps on how many of each type of weapon system, if any, each side is allowed to retain. However, national inspections teams can only verify numbers at certain territorial zones (Israel and Egypt), or 'export sites' (Florence). Some post-war agreements went even further with far more intrusive inspections, but only against roundly defeated nations, notably the Treaty of Versailles (1919).

The Conventional Armed Forces in Europe Treaty (1990) includes on-site inspections to verify conventional armament limitations among the signatories, including artillery. But CFE puts temporal and geographic limits on these inspections. Other agreements limit the export of artillery to conflict zones, such the Nairobi Protocol and the ECOWAS Convention—these efforts established mechanisms for better information sharing among member states. There are also several regional confidence building measures (e.g. India-China) that establish rules on how states can deploy artillery near specific territorial borders. But these agreements just require states to provide advance notification about military force movements—no additional verification measures are in place. These outcomes all lend strong support for our theory because states either used unilateral means to monitor compliance, or, where inspection tools were used, states crafted highly restrictive protocols to safeguard sensitive information.

Theory Support: Strong for H4.

Biotechnology

Technology Definition

Biological technology—or biotechnology—refers to techniques for making products from living organisms. Biological weapons are a specific application of this technology. According to the World Health Organization, "biological weapons are microorganisms like virus, bacteria, fungi, or other toxins that are produced and released deliberately to cause disease and death in humans, animals or plants."[1] Rudimentary biotechnology has existed for thousands of years. For instance, humans have long used selective breeding to make crops and livestock more useful as sources of food. On the military front, the deliberate infection of humans and support animals with deadly and debilitating diseases has also been an age-old tactic of war. But biotechnology is often defined more narrowly around modern methods for producing and modifying organisms, such as genetic engineering and microbiological cultures, that emerged from the biological sciences in the 20th century. We adopt this definition to focus on these modern techniques that have significant civilian and military applications.

Time Period Boundaries

Biotechnology made its modern military debut on the battlefield in 1915. The German military infected horses with biological agents to neutralize their use by adversaries in 1915, which marked the first modern use of state produced biological weapons (BW) in warfare (albeit with rather rudimentary methods).[2] In 1917, a scientist first used a pure microbiological culture to produce acetone in an industrial process.[3] We select 1915 as the debut date but using the alternative of 1917 does not change the coding of variables or outcomes.

Biotechnology has always been one of the most indistinguishable technologies when it comes to differentiating peaceful from military use—this variable remains constant over time. However, we break biotechnology into two time periods based on a major shift in integration: (1) the early industrial era from 1915–1953; (2) the biotech revolution era from 1953–2020. Modern biotechnology became highly integrated in 1953 after the discovery of the DNA structure set the foundation for scientists to launch the molecular biology revolution in the 1960s and especially early-1970s. The introduction of the Cohen-Boyer recombinant DNA technique in 1973 led to growing commercial interest in genetic engineering.

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[1] "Biological Weapons," World Health Organization, accessed January 20, 2022, https://www.who.int/westernpacific/health-topics/biological-weapons.
[2] W. Seth Carus, "A Century of Biological-Weapons Programs (1915–2015): Reviewing the Evidence," *The Nonproliferation Review* 24, no. 1–2 (January 2, 2017): 129–53, https://doi.org/10.1080/10736700.2017.1385765.
[3] Derek G. Springham, Vivian Moses, and Ronald E. Cape, *Biotechnology: The Science and the Business* (Boca Raton, FL: CRC Press, 1999).

Biotechnology, 1915–1953

Distinguishability: Low

Biotechnology has always exhibited extremely low distinguishability between peaceful and military uses. We examine this dimension across both periods of integration (1915–2020), and find that all four attributes remained constant over time. First, the small and multiuse nature of biological agents makes it difficult to draw clear distinctions based on physical properties.[4] Biotechnology has multiple applications in civilian, defensive, and offensive domains. For example, the same biological agent can be useful in peaceful medical procedures, public health research to prevent pandemics, and military weapons. Second, the development pathway for offensive weapons heavily overlaps with defensive research and broader commercial biotechnology endeavors. "The capabilities for conducting the research, development, production, and testing of biological weapons are virtually identical to those employed by defensive programs and in legitimate civilian enterprises," Gregory Koblentz concludes.[5] Most notably, ostensibly peaceful research on infectious diseases can generate knowledge and experience that could be turned into an offensive weapon. For example, scientific efforts to understand naturally occurring disease outbreaks use similar methods to cultivate and experiment with pathogens.[6] Third, the deployment pattern for biological weapons programs can look quite like peaceful or defensive medical institutes. The same equipment found in the pharmaceutical industry, for instance, can also be used to produce biological warfare agents. Koblentz points out that this allows "a nation developing biological weapons to hide its activities in civilian institutes that appear to be, or actually are, conducting legitimate pharmaceutical or medical research."[7] Indeed, it has long been difficult to identify clear biological weapons programs, as most efforts were small and hidden amid larger defensive research projects on pathogens.[8] While a few large and sophisticated bioweapons programs had unique signatures—notably pathogen stockpiles and delivery vehicles—it was hard to "distinguish between military and civilian research and between offensive and defensive research," as several studies concluded in the 1960s and 1970s.[9] Remote monitoring of facilities was insufficient to parse out civil or military uses, especially as small-scale equipment emerged in the 1990s that

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[4] For an excellent study of how the multiuse nature of biotechnology creates serious barriers to arms control, see Gregory D. Koblentz, *Living Weapons: Biological Warfare and International Security* (Ithaca, NY: Cornell University Press, 2009), chap. 2.
[5] Koblentz, 54. See also Sonia Ben Ouagrham-Gormley, *Barriers to Bioweapons: The Challenges of Expertise and Organization for Weapons Development* (Ithaca, NY: Cornell University Press, 2014).
[6] Carus, "A Century of Biological-Weapons Programs (1915–2015)," 130.
[7] Koblentz, *Living Weapons*, 66.
[8] Carus, "A Century of Biological-Weapons Programs (1915–2015)," 137, 144, 146.
[9] Milt Leitenberg, "The Question of Offensive/Defensive Distinctions in Biological Weapons Related Research, and the Potential Stimulus to BW Proliferation by Expanded Research Programs" (2004), 2, https://fas.org/man/eprint/leitenberg/off-def.pdf.

could be used for BW production.[10] Fourth, the civilian and defensive applications of biotechnology can often be rapidly converted into research on offensive weapons. There are significant challenges associated with the weaponization and delivery of biological weapons.[11] But the underlying "research, development, production, and testing activities used to develop [defensive and offensive] capabilities are similar, if not identical, in many ways," Koblentz argues.[12] This feature shrinks the amount of time needed to transform civilian biotechnology into a military asset.

Integration: <u>Low</u> (Military) / <u>Low</u> (Civilian)

Biotechnology exhibited low degrees of integration within both military organizations and the civilian economy during this period. On the offensive military side, biological warfare agents were mostly developed in secret to perform a narrow range of potential missions, often related to inflicting massive civilian casualties or disrupting military operations.[13] This led some scholars to assert that biological weapons could be a useful substitute or complement for nuclear weapons as a means of strategic deterrence.[14] In this vein, biological weapons were isolated to special units and not used at scale in modern warfare (aside from several limited cases and human experiments in the First and Second World Wars). Biological weapons programs were also expensive and often sophisticated endeavors to undertake, as the technology lay on the frontier of medical science at the time. However, the marginal cost of producing potent biological weapons can be quite low once the program matures. Research on pathogens and diseases for offensive purposes can also spillover into defensive public health efforts. On the civilian side, biotechnology remained in its infancy throughout the first half of the 20th century, with efforts largely focused on crop and livestock modification. The public health applications of biology advanced with the discovery of penicillin in 1928 and the subsequent ability to mass produce pharmaceuticals in the 1940s.[15] Despite this major leap forward, biotechnology remained at a relatively low level of integration until the biotechnology revolution expanded the range and variety of uses in the early 1950s.

Outcomes

<u>Agreement over narrow scope of activities.</u> Under the terms of the 1925 Geneva Protocol, some states agreed to prohibit the use of chemical and biological weapons

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[10] Nicholas Sims, "Verifying Biological Disarmament: Towards a Protocol and Organisation," 2000, 90.
[11] Ouagrham-Gormley, *Barriers to Bioweapons*.
[12] Koblentz, *Living Weapons*, 67.
[13] For an overview, see Gregory Koblentz, "Pathogens as Weapons: The International Security Implications of Biological Warfare," *International Security* 28, no. 3 (2003): 84–122.
[14] See, for example, S.B. Martin, "The Role of Biological Weapons in International Politics: The Real Military Revolution," *Journal of Strategic Studies* 25, no. 1 (March 1, 2002): 63–98, https://doi.org/10.1080/714004040.
[15] Robert Gaynes, "The Discovery of Penicillin—New Insights After More Than 75 Years of Clinical Use," *Emerging Infectious Diseases* 23, no. 5 (May 2017): 849–53, https://doi.org/10.3201/eid2305.161556.

against other signatories to the agreement. But states still reserved the right to produce and retaliate with such weapons; and there were no verification measures in place to monitor weapons development or use on the battlefield. The agreement was more of a no-first-use pledge rather than a deal to regulate the production or stockpiling of biological weapons or biotechnology in general.[16] In essence, states were able to surmount the dual use detection constraint by narrowing the scope of agreements to observable behaviors (using the weapons).

Theory Support: Strong for H3. This type of narrow scope agreement to curtail behavior aligns with our expectations. The case therefore provides strong support for our theory despite lacking inspections to verify compliance.

Biotechnology, 1953–2020

Distinguishability: Low

Biotechnology continued to be indistinguishable during this second period—see above.

Integration: Low (Military) / High (Civilian)

Bioweapons remained isolated within military enterprises throughout this period. The range and variety of military uses for offensive weapons underwent little change. Some nations even abandoned biological weapons programs altogether because the capability was believed to have almost no military utility.[17] However, major advances in biotechnology led to greater military focus on a wider variety of applications beyond offensive weapons. Koblentz finds that "military organizations became engaged in applying biotechnology in the areas of energy, materials science, logistics, medicine, and electronics."[18] We consider this expansion to be part of the growing integration of biotechnology within the civilian economy for commercial and defensive public health purposes. The discovery of the DNA structure in 1953 set the scientific foundation for this major expansion, but what mattered for civilian integration was the use of this knowledge to genetically engineer organisms. In 1973, the range and variety of uses for biotechnology exploded as techniques became available to genetically modify living organisms. The Cohen-Boyer recombinant DNA process led to growing commercial interest in genetic engineering. In 1982, the FDA approved the first genetically engineered drug to treat diabetes. By 2000, more than 125 genetically engineered

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[16] Nicholas A. Sims, *The Diplomacy of Biological Disarmament: Vicissitudes of a Treaty in Force 1975-85* (New York, NY: Palgrave Macmillan, 1988), 6–8; Carus, "A Century of Biological-Weapons Programs (1915–2015)," 151.
[17] This could change in the future, however. "Although biological weapons have not been used in modern times," Koblentz argues, "the diversity of available agents and the range of their effects could provide military planners with a flexible weapon system capable of carrying out a range of missions against a broad selection of targets," see Koblentz, "Pathogens as Weapons," 98.
[18] Koblentz, *Living Weapons*, 5.

drugs had been approved. The CRISPR-Cas9 gene editing process further expanded the range of applications and lowered barriers to entry.

Outcomes

Agreement but no verification protocols. States negotiated constraints in 1968–1971, culminating in the Biological Weapons Convention (BWC) of 1972, which banned the development and possession of BW and their delivery systems. But verification was "deliberately omitted from the BWC" because it would have required on-site inspection that promised to be "unacceptably intrusive to the Soviet Union."[19] In addition, the drafters of the agreement recognized that the growing integration of biotechnology within scientific and commercial enterprises around the world would have required prohibitively intrusive inspections to be effective.[20] Instead, the United States opted for "a more unilateral approach" to monitoring compliance.[21] Subsequent negotiations to enhance transparency made little progress. An effort to include a verification protocol failed in 2002, with negotiators arguing that the spread of dual use bio equipment to "almost every corner of the world" made the BWC unverifiable without intrusive inspections.[22]

In 1985, a small group of countries established the Australia Group as a multilateral export control regime to regulate the transfer of technology, components, and materials that could be used to manufacture biological and chemical weapons. But the informal group merely coordinates information sharing among member states—there are no formal verification measures.

Theory Support: Moderate for H2. The theory predicts that agreements would be nearly impossible in this zone. The outcomes—both in the type of treaty we observe and the difficulty in creating a further regime—mostly align with our expectations. The BWC was signed, but the USSR violated this agreement in ways that were difficult for the US and other states to detect. It is possible that it would have been better to have no treaty at all than to operate under one with such compliance problems. The detection challenges clearly needed intrusive inspections to address them, and our theory helps explain how the technology created a security constraint as well, making inspections too costly. Even though with in the military sphere offensive weapons were isolated, intrusive inspections of broader defensive and economic activities would have created major security and economic risks. Access to defensive research could be leveraged by an adversary for offensive purposes. Biotechnology companies also closely guarded industrial breakthroughs and trade secrets. Insisting on monitoring, as parties likely

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[19] Sims, "Verifying Biological Disarmament: Towards a Protocol and Organisation," 90.
[20] Koblentz, *Living Weapons*, chap. 2.
[21] Nicholas A. Sims, "A Simple Treaty, a Complex Fulfillment: A Short History of the Biological Weapons Convention Review Conferences," *Bulletin of the Atomic Scientists* 67, no. 3 (May 2011): 10, https://doi.org/10.1177/0096340211407400.
[22] Kenneth D. Ward, "The BWC Protocol Mandate for Failure," *The Nonproliferation Review* 11, no. 2 (June 1, 2004): 194, https://doi.org/10.1080/10736700408436972.

should have given the difficulty with distinguishing between civil and military programs, would have likely led to the agreement being rejected due to these security constraints. That pressure for monitoring did not occur may be a result of other factors, such as political need for an agreement or poor estimates about the USSR's intentions with regard to bioweapons development.

Comparison of chemical and biological cases in the context of our theory:

Both chemical and biological technology are low distinguishability but have mixed coding for integration in military vs. civilian spheres: low integration for military and high integration for civilian. In each case, we expect that consideration of military integration would have been a primary concern. Governments negotiating a potential agreement would be most concerned about whether implementing that agreement would reveal military secrets, a risk that is heightened with the more integrated a technology is within the military. But, civilian side consideration would have be a close second, as states are also keen to maintain commercial intelligence and intellectual property, and promote the scientific and economic competitiveness of the civilian side. The key question therefore is which concern—civilian or military—played the bigger role in each case. If military considerations outweigh, our theory predicts outcomes consistent with H3 (some agreements possible, scoped or narrow in scope, intrusive verification measures allowed). But, if civilian high integration issues take priority, then we expect outcomes consistent with H2 (very few agreements possible, intrusive monitoring necessary but raises prohibitively high risks).

For both cases, we, therefore, evaluated the debate between military and commercial interests over possible arms control agreements.

In the chemical case, we find that the military saw benefits to inspections and few risks, but had to contend with the interests of commercial industry which sought to avoid intrusive monitoring. However, commercial concerns were ultimately not so severe, as the industry was already highly regulated domestically. The technology was also well-developed and proliferated by the 1990s so it had relatively few secrets that would provide a significant advantage to competitors if observed. The commercial industry was convinced by government actors to accept the intrusive monitoring we ultimately see in the Chemical Weapons Convention. This outcome is consistent with the predictions of H3.

For biotechnology, the situation was reversed, with highly integrated civilian and pharmaceutical applications as the more significant concern. On the military side, distinguishability and integration were low, so to limit biological weapons, there was a recognized need to have intrusive inspections.

However, on the commercial side, advances and proprietary research were highly active, with companies and labs engaged in a wide range of applications for bio research. Biotechnology companies had strong interests in carefully guarding breakthroughs. An intrusive inspection regime would have been prohibitively costly from this point of view, as high integration created heightened risk of exposure for proprietary information. The widespread use of biotechnology in many scientific fields would have made an intrusive regime expensive to implement even in terms of inspection resources alone. Unlike in the case of the debate over the CWC, the biotechnology industry was active and strong in its opposition to inspections under the BWC.

Under these conditions, a treaty was highly unlikely. However, the BWC was signed in 1972, with the United States and Soviet Union as the primary negotiators. Here, other factors played important roles as well. For example, the United States assessed that the Soviet Union would have few incentives to cheat on an agreement (even if compliance was not verified) because the United States had seen little military benefit to biological weapons and had itself already decided to end biological weapons programs. Though it was well known that differentiating between civilian and military capabilities would be difficult, it is possible that the United States did not see a strong need to make these distinctions in an agreement, as cheating would have few benefits. In reality, the Soviet Union had made a different assessment and invested considerably in its biological weapons program. If the United States had a better assessment of Soviet intentions in this respect, it might never have accepted the BWC and its weak mechanisms.

Later efforts to revise the monitoring elements of the BWC failed in negotiations. The need for more intrusive monitoring to distinguish banned military capabilities was even more apparent but continued to be prohibitively costly for the civilian side. These outcomes are mostly consistent with H2, where the BWC is highly constrained by the dual use characteristic of biotechnology, and follow on agreements failed.

Chemical

Technology Definition

"Chemical" technology refers to discrete chemicals and the modern means of producing such substances that emerged after 1850. We further focus the definition to chemicals (and attendant production facilities) with the potential to be used as weapons. The military and civil use of such chemicals varies along a spectrum.[1] At one end, some chemicals are pure warfare agents whose main purpose is to cause death or harm. There are few peaceful uses for these substances and their immediate precursors. In the middle are chemicals with legitimate commercial uses that can be diverted to produce warfare agents. At the other end are widely available chemicals with extensive civil uses, such as chlorine, that can still be weaponized into lethal agents. This makes many chemicals and chemical production facilities dual use in nature.[2]

Time Period Boundaries

Scholars commonly use 1850 as the debut date for the modern chemical manufacturing industry because new production processes were developed to meet the exponential growth in demand during the Industrial Revolution. At first, the chemical industry focused on large scale production of acids and alkalis as inputs to other industries (e.g., textiles and steel). But three types of innovations began to emerge with greater frequency: (1) processes for the mass production of natural but rare chemicals, notably the Haber-Bosch nitrogen fixation process (1912) and synthetic indigo process (1897); (2) improvements in the efficiency of industrial production processes, such as the Solvay ammonia soda process (1864); and (3) the creation of chemical substances that do not occur naturally, such as synthetic dyes (1856) and pharmaceuticals. These advances in chemical production helped to expand the range and variety of uses for chemical substances. From 1850 to 2000, the chemical industry went from producing a few important heavy chemicals to developing a “diverse product portfolio of well over

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[1] This categorization draws upon the Annexes of the Chemical Weapons Convention (CWC), which outline three “Schedules”, or categorical lists, of chemicals that can be classified based on their commercial and peaceful utility and availability. Schedule 1 chemicals are known as chemical warfare agents (CWAs), insofar as they and their most immediate precursors have limited peaceful utility or commercial application and have been traditionally weaponized within military CW programs, such as sulfur mustard agent, ricin, and sarin. Schedule 2 chemicals are those that are dual-use, can have legitimate commercial applications in small quantities, but can be diverted to CWA production. Schedule 3 chemicals are those that are dual-use, readily available in large quantities, and have significant commercial applications, such as chlorine. Despite their wide availability and great commercial utility, Schedule 3 chemicals like chlorine can also be easily weaponized to cause harm in mass effect scenarios. See “Annex on Chemicals,” *Organisation for the Prohibition of Chemical Weapons* (Accessed July 29, 2021), retrieved from: https://www.opcw.org/chemical-weapons-convention/annexes/annex-chemicals/annex-chemicals.

[2] Jonathan B. Tucker, *Innovation, Dual Use, and Security: Managing the Risks of Emerging Biological and Chemical Technologies* (Cambridge, MA: MIT Press, 2012).

70,000 different chemical substances," one scholar estimates.[3] However, we treat chemical technology as a single case study because the chemical industry reached a high level of integration by the end of the 19th century. Subsequent innovations—such as advances in polymer chemistry during the 1930s and 1940s—only further reinforced this trend. As described in detail below, chemical technology also quickly became highly integrated into the broader production base for military capabilities. By the dawn of the First World War, for example, chemicals and chemical production had already become integral to the manufacture and use of conventional military systems (e.g., explosive compounds or petroleum fuel). Chemical weapons were also introduced on the battlefield during this time. But these specialized weapons remained isolated from other military assets.

Chemicals, 1850–2020

Distinguishability: Low

The distinguishability of chemical technology is quite low across the entire civil-military use spectrum for four reasons. First, the observable physical properties of many chemicals reveal little information about their underlying composition. For example, the deadly nerve agent sarin and the common industrial compound ethylene glycol are both clear, colorless, and odorless liquids. Environmental sampling techniques are needed to differentiate one chemical from another.[4] Second, the production of chemical warfare agents can look similar to benign chemical manufacturing processes. From the outside, it may not be clear what exactly is being made in a chemical plant, as much of the equipment and infrastructure is multi-purpose.[5] Dedicated single purpose military production sites may have unique "fingerprints," but such facilities are not necessary to manufacture lethal agents.[6] Commercial multi-purpose plants produce a wide range of chemicals and precursors, some of which can be diverted for military use. Third, the deployment of chemical weapons involves telltale signs, such as mobilizing special units or unique delivery platforms. Prior to actual employment, however, chemical warfare agents can be masked as toxic chemicals intended for civil applications, especially poisonous gases with major industrial uses, such as phosgene and chlorine.[7] Fourth,

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[3] See Johann Peter Murmaun, "Chemical Industries after 1850," Oxford Encyclopedia of Economic History (Oxford University Press, 2003).
[4] Mark F. Mullen, Kenneth E. Apt, and William D. Stanbro, "Criteria for Monitoring a Chemical Arms Treaty: Implications for the Verification Regime," Center for National Security Studies, Los Alamos National Laboratory, December 1991.
[5] On the relative versatility of pilot versus commercial scale multi-purpose production plants, see H. Schroder and H. Hoffmann, "Some Views on the Control of Multi-Purpose Plants," in SIPRI, *Non-Production by Industry of Chemical-Warfare Agents: Technical Verification under a Chemical Weapons Convention,* Edited by S.J. Lundin, 1988, 108-109.
[6] Benoit Morel, "Verifiability and Enforceability of the Chemical Weapons Convention," in *Shadows And Substance: The Chemical Weapons Convention*, ed. Benoit Morel and Kyle Olson (Boulder, CO: Westview Press, 1993), 194.
[7] Brad Roberts, *Chemical Disarmament and International Security*, Adelphi Papers No. 267 (London, UK: International Institute for Strategic Studies, 1992), 22–27.

many civilian chemical production capabilities can be quickly converted to manufacture chemical warfare agents.

Integration: <u>Low</u> (Military) / <u>High</u> (Civilian)

The integration of chemical technology varies dramatically from low to high across the military and civilian divide. On the military side, chemical warfare agents have been isolated to niche units who perform a limited range of tasks. During the First World War, for example, Charles Heller finds that "the major combatants realized that the employment of gas called for specially trained troops and, accordingly, formed offensive gas units."[8] Despite having significant effects on the battlefield, chemical weapons were used in narrow ways to overcome the defensive advantage in trench warfare at the time.[9] The range and variety of uses for chemical warfare agents remained limited in the decades ahead, even amid the emergence of more lethal compounds and delivery systems.[10]

However, several key qualifications are in order. First, the production base for chemical weapons can be more integrated within the military and especially within the civilian economy. There are many uses for lethal, toxic, and precursor chemical substances beyond making chemical weapon agents. Second, the military has long made extensive use of chemicals and chemical manufacturing processes that are not related to chemical warfare at all. Common industrial chemicals have many different military uses. More exotic foams and special resins have been instrumental to advanced weapons systems. However, the high integration of "chemicals" writ large into the military is distinct from the isolated nature of chemical warfare agents.

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[8] Charles E. Heller, "Chemical Warfare in World War I: The American Experience, 1917–1918," Combat Studies Institute, U.S. Army Command and General Staff College, September 1984, https://webharvest.gov/peth04/20041017045619/http:/www.cgsc.army.mil/carl/resources/csi/Heller/HELLER.asp.

[9] Gerald J. Fitzgerald, “Chemical Warfare and Medical Response During World War I,” *American Journal of Public Health* 98:4 (April 2008), retrieved from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2376985/#__sec1title; Edward M. Spiers, “Deterrence and Disarmament: Responses to Chemical and Biological Warfare, 1919-93,” *A History of Chemical and Biological Weapons* (Reaktion Books, 2010); Jonathan Tucker, *War of Nerves: Chemical Warfare from World War I to Al-Qaeda* (New York, NY: Anchor, 2007).

[10] Stephen L. McFarland, ”Preparing for What Never Came: Chemical and Biological Warfare in World War II,” *Defense Analysis* 2:2 (1986); John Ellis van Courtland Moon, “Chemical Weapons and Deterrence: The World War II Experience,” *International Security* 8:4 (Spring 1984); Director of Central Intelligence, “Impact and Implications of Chemical Weapons Use in the Iran-Iraq War,” U.S. Central Intelligence Agency (March 22, 1988), https://www.cia.gov/library/readingroom/docs/DOC_0001079783.pdf; Rebecca Hersman, Suzanne Claeys, and Cyrus Jabbari, “Rigid Structures, Evolving Threat: Preventing the Proliferation and Use of Chemical Weapons,” Center for Strategic and International Studies (December 18, 2019), retrieved from: https://www.csis.org/analysis/rigid-structures-evolving-threat-preventing-proliferation-and-use-chemical-weapons.

The modern civilian chemical industry has been highly integrated into virtually all sectors of the economy since its genesis in the 19th century.[11] Chemical production capabilities have long provided critical inputs to many different industries. Today, it is one of the largest manufacturing sectors in the world, with thousands of facilities producing a wide range of extensively used chemicals worth $3-4 trillion every year. The chemical industry has also generated spillover effects, adopting and developing new technologies and manufacturing processes. Given the potential for many toxic chemicals to harm people and the environment, the industry has long been subject to heavy regulation and inspection by domestic authorities. "In many countries," one industry leader noted, "government regulation of chemical manufacturing requires extensive reporting on many major and minor aspects of a particular manufacturing plant's operations."[12] Chemical technology is therefore highly integrated and monitored to manage negative externalities from commercial applications.

Outcomes

Agreement with intrusive verification regime.

States convened in 1899 and in 1907 in international Peace Conferences at The Hague and agreed to "abstain from the use of projectiles the sole object of which is the diffusion of asphyxiating or deleterious gas." The Hague Declarations of 1899 and 1907 were the first instance of international cooperation to control chemical weapon use, but were non-binding and too narrowly scoped. In the wake of the First World War, forty-four states convened to sign the 1925 Geneva Protocol, which prohibited the use of chemical and biological weapons, but again was limited in not addressing defensive chemical weapons or dual use technology research and development, production, possession, or transfer.[13]

In 1980, states began to negotiate an agreement for the total prohibition of chemical weapons under the auspices of the United Nations Committee on Disarmament. The Western states, led by the US, considered verification via mandatory on-site inspections "as a prerequisite for the conclusion of a comprehensive treaty."[14] After the Soviet Union accepted this position in 1987, the focus began to shift to "'industrial questions,' i.e. the verification of non-production of CW in the civil chemical

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[11] SIPRI, *The Chemical Industry and the Projected Chemical Weapons Convention, Vol. 1, Proceedings of a SIPRI/Pugwash Conference* (Oxford, UK: Oxford University Press, 1986), 37.
[12] Will D. Carpenter, "Government Regulation of Chemical Manufacturing in the USA as a Basis for Surveillance of Compliance with the Projected Chemical Weapons Convention," in SIPRI, *The Chemical Industry and the Projected Chemical Weapons Convention, Vol. 2*, *Proceedings of a SIPRI/Pugwash Conference* (Oxford, UK: Oxford University Press, 1986), 11. See also Will D. Carpenter, "The Perspective of the Western Chemical Industry," in *Shadows And Substance: The Chemical Weapons Convention*, ed. Benoit Morel and Kyle Olson (Boulder, CO: Westview Press, 1993), 120.
[13] Jean Pascal Zanders, "The CWC in the Context of the 1925 Geneva Debates," *The Nonproliferation Review* (Spring-Summer 1996).
[14] Thomas Bernauer, "The Projected Chemical Weapons Convention: A Guide to the Negotiations in the Conference on Disarmament," United Nations Institute for Disarmament Research Geneva, UNIDIR/90/7, https://unidir.org/sites/default/files/publication/pdfs/the-projected-chemical-weapons-convention-a-guide-to-the-negotiations-in-the-cd-en-100.pdf, 21.

industry."[15] According to a report from the United Nations, the need to verify compliance at thousands of installations around the world created "a dilemma."[16] Although intrusive inspections were deemed essential, states worried about their ability to protect military facilities unrelated to chemical warfare, as well as confidential trade secrets.[17] These concerns were eased in two ways. First, the convention placed some limits on 'anytime, anywhere' inspections. "Inspectors would be granted physical access to any site, but inspected parties would be allowed to 'manage access,' including to lock data or equipment in safes and to shroud sensitive equipment."[18] This would safeguard secret military facilities producing chemicals for use in conventional or strategic weapon systems. Second, the chemical industry already operated under domestic inspections in many countries, so they helped state negotiators craft procedures to safeguard proprietary commercial information. These measures paved the way for states to open for signature the Chemical Weapons Convention (CWC) in the early-1990s.[19]

In 1985, a small group of countries established the Australia Group as a multilateral export control regime to regulate the transfer of technology, components, and materials that could be used to manufacture biological and chemical weapons. However, the informal group merely coordinates information sharing among member states—there are no formal verification measures.

Theory Support: Strong for H3. *For a detailed analysis, see the comparison of our theoretical expectations for the chemical and biological technology cases at the end of Biotechnology study above.*

[15] Bernauer, "The Projected Chemical Weapons Convention," 26.
[16] Bernauer, "The Projected Chemical Weapons Convention," 53.
[17] Stephen Black, "Illuminating the Shadows: On-Site Inspections and the Chemical Weapons Convention," in *Shadows And Substance: The Chemical Weapons Convention*, ed. Benoit Morel and Kyle Olson (Boulder, CO: Westview Press, 1993), 197. See also Roberts, *Chemical Disarmament and International Security*, 35.
[18] Jessica Eve Stern, "Lethal Compounds: The New Chemical Weapons Ban," *The Brookings Review* 12, no. 3 (1994): 33, https://doi.org/10.2307/20080489.
[19] The CWC established a governance and implementation body to execute one of the most complex and intrusive inspection regimes for an arms control agreement. The treaty text prohibits the use, research, development, production, possession, and transfer of CW and requires States Parties to declare their CW stockpiles and production facilities and commit to their destruction. Annexes of the CWC outline three "Schedules", or categorical lists, of chemicals that can be classified based on their commercial and peaceful utility and availability. Since the CWC's entry-into-force (EIF) in 1997, nearly the entire international community has acceded to the Treaty, except for four outlier states (North Korea, Egypt, Israel, and South Sudan). See Stefano Costanzi and Gregory D. Koblentz, "Updating the CWC: How We Got Here and What is Next," *Arms Control Today* (April 2020), https://www.armscontrol.org/act/2020-04/features/updating-cwc-we-got-here-what-next; Julia Masterson, "Reinforcing the Global Norm Against Chemical Weapons Use," *Arms Control Association* (February 18, 2021), https://www.armscontrol.org/policy-white-papers/2021-02/reinforcing-global-norm-against-chemical-weapons-use.

Conventional Explosives

Technology Definition

"Conventional explosives" are materials that generate a rapid release of energy via mechanical methods or chemical reactions.[1] We focus on "high order" explosive materials that cause a destructive shockwave by burning faster than the speed of sound, such as nitroglycerin, dynamite, and plastic explosives.[2] By contrast, "low order" explosives burn below the sound barrier and are commonly found in other technologies, notably the ammunition for firearms or the propellant for missiles. Low order explosives such as black powder were used in rudimentary projectile weapons dating back to the 10th century and in civilian mining operations starting in 1627.[3] The modern chemical industry birthed a series of more powerful high explosives during the industrial revolution, starting with nitroglycerin (1847), dynamite (1867), plastic gelignite (1875), TNT (1891), PETN (1894), and RDX (1899).[4] Although many of these compounds were first developed for use in large construction projects and mining operations[5], their destructive power made them useful for military purposes, with shaped charges and other special rounds developed for battlefield use in the late-19th century.[6]

Time Period Boundaries

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[1] For an overview, see Tenney L. Davis, *The Chemistry of Powder and Explosives* (Hollywood, CA: Angriff Press, 2012); Gerard Arthus, "Explosives and Demolitions" (Washington, DC: U.S. Department of the Army, June 15, 1992), http://archive.org/details/FM_5_250_Explosives_And_Demolitions_.

[2] In a weapon device, high explosives can work in combination with other elements, notably incendiary materials, to damage the target. We do not explicitly consider incendiary devices as a separate category because the dual use characteristics are similar and often rely on conventional explosives to trigger ignition.

[3] Andreas G. Heiss and Klaus Oeggl, "Analysis of the Fuel Wood Used in Late Bronze Age and Early Iron Age Copper Mining Sites of the Schwaz and Brixlegg Area (Tyrol, Austria)," *Vegetation History and Archaeobotany* 17, no. 2 (2008): 211–21.

[4] Colin F. Baxter, *The Secret History of RDX: The Super-Explosive That Helped Win World War II* (Lexington, KY: University Press of Kentucky, 2018). For contemporary accounts at the time, see Tom Gregorie Tulloch, ed., *The Rise and Progress of the British Explosives Industry* (London, UK: Whittaker and Co., 1909), http://archive.org/details/riseprogressofbr00interich; Arthur Marshall, *A Short Account of Explosives* (Philadelphia, PA: P. Blakiston's Son & Co, 1917), http://archive.org/details/ashortaccountex00marsgoog.

[5] Arthur Pine Van Gelder and Hugo Schlatter, *History of the Explosives Industry in America* (New York, NY: Columbia University Press, 1927), http://www.degruyter.com/document/doi/10.7312/geld91436/html; *Farmers' Hand Book of Explosives: Instructions in the Use of Explosives for Clearing Land, Planting and Cultivating Trees, Drainage, Ditching, Subsoiling and Other Purposes* (Wilmington, DE: E.I. du Pont de Nemours & Company, 1920), http://archive.org/details/farmershandbook00deptgoog.

[6] Donald R. Kennedy, "History of the Shaped Charge Effect: The First 100 Years" (Alexandria, VA: Defense Technical Information Center, March 30, 1990), http://www.pyrobin.com/files/Shaped%20Charge%20Effect.pdf; Gerard Arthus, "Military Explosives" (Washington, DC: U.S. Department of the Army, September 20, 1984), http://archive.org/details/TM_9_1300_214_Military_Explosives_.

We code the debut of modern conventional explosives in 1847 with the development of nitroglycerin for use in large earth excavation projects. We treat the technology as a single case study because both dual use attributes remained stable over time.

Conventional Explosives,1847–2020

Distinguishability: High

The dual use distinguishability of explosive technology is quite high in most contexts. Conventional explosives that are designed for use in military applications tend to be highly distinguishable due to their unique arrangement and deployment. Fragmentation, flechette, and other anti-personnel explosives (e.g., grenades and mines) are clearly observable as weapons with no peaceful use. Even shaped charges, which are used extensively in commercial industry, look different when operationalized into high explosive anti-tank (HEAT) warheads. However, explosives that begin life as a civilian design can be repurposed to cause destruction on the battlefield, albeit with less optimal effects than their military designed counterparts. In many countries, civilian users therefore face stringent domestic regulations that limit the use, transport, and storage of conventional explosives for peaceful applications.[7] But the weaponization of explosives in the military sets them apart from their civilian counterparts.

Integration: High (Military) / High (Civilian)

Conventional explosives are highly integrated within many military weapons systems and key sectors of the civilian economy. High explosives are used in artillery shells, antipersonnel and antitank mines, grenades, shaped warheads, breeching charges, and a wide range of bombs. Low order explosives are instrumental as a propellent for ammunition, rockets, and missiles, as well as time delay fuses.[8] Explosive technology is considered in almost every development of military capabilities. This is because most everything developed for use in physical domain combat could be involved in an explosive event at some point. For example, vehicles, airplanes, ships, personal protective equipment, generators, and structures are all developed to better employ and/or defend against the use of explosives. On the civilian side, conventional explosives are used in a variety of industrial engineering and mining projects, from controlled demolition and excavation to oil well perforation. Specialized explosive

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[7] See, for example, “Safety in the Handling and Use of Explosives” (New York, NY: Institute of Makers of Explosives, 1940), http://archive.org/details/gov.law.ime.explosives.1940; “Federal Explosives Law and Regulations” (Washington, DC: U.S. Department of Justice, Bureau of Alcohol, Tobacco, Firearms and Explosives, 2012), https://www.atf.gov/explosives/docs/report/publication-federal-explosives-laws-and-regulations-atf-p-54007/download; “Explosives: Licensing,” Health and Safety Executive, accessed October 11, 2021, https://www.hse.gov.uk/explosives/licensing/index.htm.
[8] R. H. Kent, “Explosives and Their Military Applications,” *Journal of Applied Physics* 13, no. 6 (June 1, 1942): 348–54, https://doi.org/10.1063/1.1714877; William H. Rinkenbach and L. F. Audrieth, “Modern Military High Explosives,” *Journal of Chemical Education* 22, no. 11 (November 1, 1945): 522, https://doi.org/10.1021/ed022p522.

charges are also central to several safety technologies, notably emergency ejection, airbags, and avalanche control.[9] Given the maturity of chemical manufacturing processes, the marginal cost of production for most conventional explosives is quite low. In addition, advances in explosive technology often spillover into new use opportunities. For example, the ability to rapidly release small quantities of energy with sodium azide opened development of airplane escape cuts and automobile airbags.[10]

Outcomes

<u>Agreements to limit specific weapons with unilateral collection methods.</u>
Conventional explosives have occasionally been subjected to formal arms control limits, such as the Hague Convention on the Laying of Submarine Mines (1907), the Convention on Certain Conventional Weapons (1981), the Protocol on Prohibitions or Restrictions on the Use of Mines, Booby-Traps and Other Devices (1996), and especially the Ottawa Mine Ban Treaty (1999). However, the agreements all depend on unilateral methods to monitor compliance. This low transparency level is hardly surprising given the military utility and extensive integration of the technology. Although explosives are highly distinguishable, an agreement to limit their military applications would generate severe security risks if it employed cooperative verification measures.

The Ottawa Treaty (1999), for example, bans the production and development of anti-personnel mines, but lacks an intrusive inspection regime to verify compliance. Instead, Findlay notes that the treaty "relies totally on self-reporting for its 'baseline' data and subsequent data acquisition," backed by unilateral intelligence collection of signatory states.[11] For suspected violations, the treaty does include the possibility of challenge inspections, but Findlay points out that these involve "managed access" techniques "to protect sensitive equipment, information and areas."[12] As a result, the outcomes lend strong support for our theory.

Theory Support: <u>Strong for H4.</u> These outcomes all lend strong support for our theory because states used unilateral means to monitor compliance.

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[9] Abromeit, "United States Military Artillery for Avalanche Control Program: A Brief History in Time."
[10] William L. Bell, "Chemistry of Air Bags," *Journal of Chemical Education* 67, no. 1 (January 1, 1990): 61, https://doi.org/10.1021/ed067p61.
[11] Trevor Findlay, "Verification of the Ottawa Convention: Workable Hybrid or Fatal Compromise?," in *Disarmament Forum: Framework for a Mine-Free World*, ed. Kerstin Hoffman, 1999, 46, https://www.unidir.org/files/publications/pdfs/framework-for-a-mine-free-world-en-367.pdf.
[12] Findlay, 48.

Cruise Missiles

Technology Definition

A cruise missile is "an unmanned self-propelled guided vehicle that sustains flight through aerodynamic lift for most of its flight path."[1] The majority of a cruise missile's flight path is maintained at a constant speed. Cruise missiles are propelled by engines, often rocket, turbofan, or turbojet engines, and can be launched from multiple different types of platforms including ground, air, or sea.[2] Cruise missiles remain within the atmosphere for the duration of their flight. Whereas ballistic missiles are categorized based on their range, cruise missiles are primarily categorized by their speed, including categories of subsonic, supersonic, and hypersonic. By definition, a cruise missile's primary mission is to deliver a payload to a target. This suggests that most, if not all, applications of cruise missiles are military in nature. While certain unmanned aerial vehicles (UAVs) and unmanned control-guided helicopters or aircraft can have similar features and subsystems, they are analytically distinct because a cruise missile's explicit designed purpose is for warhead delivery.[3]

Time Period Boundaries

Cruise missile technology made its operational debut in 1944 with the infamous Vergeltungswaffen-1 (V-1)—a new type of early cruise missile developed at the Nazi German air force Peenemünde laboratory. The weapon, also known as the "flying bomb," was first used by the Germans to attack London beginning in 1944.[4] From 1945-1948, the United States began to develop several similar projects, culminating in cruise missiles that could be launched from air, sea, and ground platforms.[5] By the late 1960s

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[1] "Glossary: Cruise Missile," *Nuclear Threat Initiative,* https://www.nti.org/learn/glossary/#C.
[2] "Cruise Missile Basics," *Missile Defense Advocacy Alliance,* https://missiledefenseadvocacy.org/missile-threat-and-proliferation/missile-basics/cruise-missile-basics/.
[3] Ibid.
[4] The V-1 relied on a pulse jet for propulsion and had to be launched from the ground via a catapult to ignite the engine. Once the engine was ignited, the missile could attain speeds from 150-400 miles per hour. In terms of guidance, the missile contained a gyroscope and compass, as well as a barometric altimeter for altitude control. Because of its rudimentary design, the missile could only operate at high altitudes with a limited range and was suspectable to being shot down by British forces. Conversely, the basic design allowed the Germans to produce many missiles cheaply and quickly. From 1944 to March of 1945, approximately 30,000 V-1s were manufactured, 25,000 were launched against England and Belgium, only 7,000 hit land in England, and fewer than 4,000 landed in the London area, see John T. Correll, "Hitler's Buzz Bombs," *Air Force Magazine,* 1 March 2020, https://www.airforcemag.com/article/hitlers-buzz-bombs/.
[5] The Snark was designed to be a nuclear capable cruise missile with a jet engine propulsion system and was deployed in the late 1950s, despite several guidance system issues. The Navaho was a supersonic missile with a ramjet engine. However, the missile performed poorly, and the Navaho program was canceled in 1958 without official deployment. The Matador was a ground launched subsonic missile that was deployed from 1954 to 1962, when it was phased out due to guidance system inaccuracies. During the same time frame, the U.S. Navy designed a sea-launched cruise missile that was operational from 1955-1959; and in the early 1960s-1976, the U.S Air Force developed air launched cruise missiles.

to early 1970s, there were several advancements in guidance systems as well as engine developments that resulted in the US deploying more advanced cruise missiles by the end of the Vietnam war. Of the various cruise missiles that were developed during this time, perhaps most notable is the Tomahawk cruise missile. Following the deployment of the Tomahawk by the United States, several countries in the Middle East, South Asia, and Northeast Asia began developing cruise missile programs, likely beginning around the early 1990s.[6] While there have been recent technological advances in cruise missile technology due to improved information processing, much of the cruise missile technology continues to be based on technology developed in the 1960s.[7] As a result, we treat cruise missiles as a single case study because the dual use technology attributes remained constant over time.

Cruise Missiles, 1944–2020

Distinguishability: High

Cruise missiles are distinguishable as a military platform for two main reasons. First, the physical characteristics of this weapon system are unique and not widely found in other military or civilian platforms. Cruise missiles are made of several subsystems, including propulsion and guidance systems, payload, and an airframe. To be sure, some subcomponent technologies in cruise missiles, such as guidance and propulsion systems, can be used in UAVs and other peaceful aircraft. But several observable features separate cruise missiles from their closet civilian analogues. The airframe is the body of the missile that holds together the propulsion, guidance, and payload systems. Often, in cruise missiles, the airframe has small wings and a tail to provide stability and flight control. The propulsion system consists of the missile's engine and associated oxidizer and propellant.[8] The propulsion system ultimately determines the range, altitude, and speed of the cruise missile. Because the propulsion system effects the altitude, it can also help the cruise missile evade missile defenses. Altering the flightpath, trajectory, and/or altitude of the missile helps to avoid detection by missile defense radars and sensors. The guidance system helps to ensure that the cruise missile follows the correct flight path and accurately strikes the final target. Because cruise missiles are designed to change their trajectory, two different types of guidance

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[6] See Bryan Robert Early et al., "Climbing the Ladder: Explaining the Vertical Proliferation of Cruise Missiles," *Journal of Conflict Resolution*, April 8, 2022, 00220027221079399, https://doi.org/10.1177/00220027221079399.
[7] Most recent advancements that have improved cruise missile accuracy and missile defense evasion capabilities, including improved guidance and propulsion systems. For example, in the latest upgrade of the Tomahawk series cruise missiles, the missile's guidance system can be rerouted while the missile is in-flight. The missile also has a faster launch time and loitering capability because of its advanced propulsion system. For an overview, see "Tomahawk," *Missile Threat: Center for Strategic and International Studies Missile Defense Project,* https://missilethreat.csis.org/missile/tomahawk/.
[8] Fabian Hoffmann, "Cruise missile proliferation: Trends, strategic implications, and counterproliferation," *The European Leadership Network,* March, 2021, https://www.europeanleadershipnetwork.org/wp-content/uploads/2021/03/Fabian_Final-2.pdf.

are required: midcourse and terminal.[9] Methods for guidance vary depending on the missile, but generally, midcourse guidance provides locational awareness and terminal guidance seeks to identify and strike the target. The payload is the warhead that is dropped or delivered to the final target.

Second, cruise missiles are often deployed for military use ways in ways that diverge from the civilian applications of UAVs or commercial aircraft. States almost always deploy cruise missiles on air, sea, or ground launch platforms, such as bombers, battleships or submarines, or mobile missile launchers. In theory, it may be possible to disguise the launch tube for a cruise missile within a civilian naval vessel or airliner. But nations tend to eschew this type of conversion in favor of using clear military launch platforms that improve cruise missile accuracy and performance.

The development attribute cuts against the grain of the other attributes to some extent. Cruise missile development can overlap with commercial aircraft production. The problem is that dual use subsystems, notably propulsion and guidance technologies, have peaceful aerospace applications.[10] This issue can make it difficult to draw firm evidence of cruise missile development.[11] For example, Pakistan developed its Babur cruise missile largely in secret as production occurred alongside conventional aircraft production. But we still code cruise missiles as highly distinguishable because the military applications of the technology are readily observable upon deployment.

Integration: <u>High</u> (Military) / <u>Low</u> (Civilian)

Cruise missiles are highly integrated within the military but serve no purpose within the civilian realm. This means that the technology receives a mixed coding of high military integration and low civilian integration. On the military side, the technology scores high along all three attributes of integration. First, cruise missiles can perform a wide range and variety of missions with different capabilities (i.e., speed, targets, and launch capabilities). The weapon system tends to be deployed alongside an aircraft, ship or submarine, or ground launch platform. For example, depending on the variant, Tomahawk cruise missiles can be sea or ground launched, can be used against land or sea assets, and can carry conventional or nuclear warheads.[12] While the Tomahawk has made several advancements since its original deployment, the missile continues to largely rely on technology that is based on developments from the 1960s.[13] This technology largely includes a Tercom guidance system and turbofan engine propulsion

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[9] "Cruise Missile Basics," *Missile Defense Advocacy Alliance.*

[10] The development of more advanced propulsion and guidance subsystems also makes it possible to transform existing missile systems into more advanced cruise missile system. For example, the Chinese Silkworm missile could be transformed from a short-range anti-ship cruise missile to a longer-range land attack cruise missile using only commercially available component technology. But this does not shape the civil-military distinguishability problem as much.

[11] Ibid., 55.

[12] "Tomahawk," *Missile Threat: Center for Strategic and International Studies Missile Defense Project,* https://missilethreat.csis.org/missile/tomahawk/.

[13] Dennis M. Gormley, *Missile Contagion: Cruise Missile Proliferation and the Threat to International Security,* Naval Institute Press: Annapolis, 2008, 91.

system. By 1996, cruise missiles were being used in large numbers in combat for the first time since WWII. During the two wars in Iraq, land attack cruise missiles became a preferred tactic of the United States because of their accuracy and because they did not put pilots at risk.[14] The Iraq wars also demonstrated that cruise missiles could effectively be used together with ballistic missiles to evade missile defenses. Second, cruise missiles are more cost effective than manned aircraft if their attrition rate can effectively be managed.[15] In 2000, US Air Force Lt. Col. David Nicholls argued that “so long as cruise missile attrition is less than 80 percent, cruise missiles are more effective than manned aircraft.”[16] Finally, advances in cruise missile technology has also led to advances in other technology categories such as hypersonic missiles and advanced UAVs.

Outcomes

Agreements with unilateral collection or inspection phase out (limits). The mixed integration attribute (high military but low civilian integration) means that inspecting compliance with an agreement on cruise missiles could reveal other military capabilities but does not increase any costs via the civilian side. The overall costs from inspections should be lower than for technologies which are integrated in both civilian and military sectors. As is the case with ballistic missiles (see Rockets), intermediate and low range cruise missiles are more likely to be integrated within the military as compared to strategic range capabilities, which are also more likely to be part of a state's nuclear arsenal. Thus, the lower range capabilities would be more difficult to inspect and would expect agreements to rely on national technical means or clearly circumscribed monitoring (consistent with H4). Along these lines, the Missile Technology Control Regime (MTCR) is a voluntary multilateral body that seeks to coordinate national export licensing efforts to prevent missile proliferation.[17] The MTCR was adopted in 1987 and classifies cruise missiles as a Category I system, alongside unmanned arial vehicles. The MTCR does not have stringent enforcement mechanisms, as we expect for technologies in the H4 box.

In line with H4, states also phased out inspections to limit disclosure damage associated with observing cruise missile technology. The Intermediate-Range Nuclear Forces (INF) treaty between the United States and the Soviet Union/Russia, signed in 1987, banned all nuclear and conventional ground-launched ballistic and cruise missiles with intermediate ranges (500–5,500 km). The treaty called for an elimination of these missiles, which was verified with inspections, but after a set period, states would rely on their intelligence capabilities rather than inspection of military areas. Phasing out inspections helped to dampen the security risks associated with long-term observation of military units and installations This avoided the security costs states might incur if an adversary were allowed to continue to inspect military units or installations which might

[14] Ibid., 51.
[15] In this case, attrition refers to the ability to reuse airborne military assets.
[16] Ibid., 49.
[17] “Our Mission,” *Missile Technology Control Regime,* https://mtcr.info.

in theory deploy intermediate range cruise or ballistic missiles. When the US detected a violation of the INF by Russia in 2014, it was via its own intelligence capabilities not any inspection mechanism.[18] The United States withdrew from the INF treaty in 2019, citing Russian non-compliance due to their cruise missile deployment. The INF limits and inspections regime outcome leads us to code the cruise missile case as offering strong support for H4.

Finally, it is worthwhile to note that there have been comparatively less attempts at limiting cruise missile technology than there has at limiting ballistic missile technology (see, for example, the Hague Code of Conduct against Ballistic Missile Proliferation).

Theory Support: <u>Strong for H4</u>. These outcomes all lend strong support for our theory because states either used unilateral means to monitor compliance, or, where inspection tools were used, states crafted highly restrictive protocols to safeguard sensitive information (e.g., temporal phase out in the INF treaty).

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[18] Daryl Kimball and Kingston Reif, "The Intermediate-Range Nuclear Forces (INF) Treat at a Glance," *Arms Control Association,* August 2019, https://www.armscontrol.org/factsheets/INFtreaty.

Cyber

Technology Definition

"Cyber" or "information technology" (IT) refers to the computers and networks that enable users to create, process, store, and exchange electronic data. IT enables an extensive range of civilian and military activities but is not itself a weapon system. We therefore focus on the specific applications of IT designed to gain unauthorized access to computer systems or to deny, degrade, or disrupt them. These so-called "cyber weapons" include all families of malware (trojans, viruses, and worms), and network-based attacks such as denial of service and code injection.[1] The term "weapon" belies the peaceful or benign uses of such cyber capabilities, notably in enabling civilian actors to test their network defenses against potential attackers. For example, the information security team for an investment bank may need the latest cyber weapons on hand to identify and patch network vulnerabilities. As a result, cyber weapons are intrinsically dual use in nature.[2]

Time Period Boundaries

Cyber weapons emerged soon after the birth of modern IT systems with ARPANET in 1969.[3] The TCP/IP communication protocol suite at the heart of this new network was not designed to be secure, which left the technology vulnerable to cyber weapons.[4] Subsequent increases in processing power and network connectivity expanded the attack surface. We treat the technology as a single case study because both dual use attributes remained stable over time.

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[1] For a similar definition, see Herbert Lin, “Governance of Information Technology and Cyber Weapons,” in *Governance of Dual-Use Technologies: Theory and Practice*, ed. Elisa Harris (Cambridge, MA: American Academy of Arts and Sciences, 2016), 112–14.
[2] Scholars have identified dual use as a core characteristic of cyber weapons. See Raymond C. Parks and David P. Duggan, “Principles of Cyberwarfare,” *IEEE Security Privacy* 9, no. 5 (September 2011): 30–35, https://doi.org/10.1109/MSP.2011.138.
[3] Sharon Weinberger, *The Imagineers of War: The Untold Story of DARPA, the Pentagon Agency That Changed the World* (New York, NY: Knopf, 2017).
[4] See Barry M. Leiner et al., “A Brief History of the Internet,” *ACM SIGCOMM Computer Communication Review* 39, no. 5 (October 7, 2009): 22–31, https://doi.org/10.1145/1629607.1629613. Denning reports the early use of cyber weapons in the 1970s as “a program that loaded itself into an idle workstation, disabled the keyboard, drew random pictures on the screen, and monitored the network for other idle workstations to invade,” see Peter J. Denning, “Computer Viruses,” The Science of Computing for American Scientist 76, no. 3 (June 1988), https://ntrs.nasa.gov/api/citations/19890017050/downloads/19890017050.pdf.

Distinguishability: Low

Cyber weapons are highly indistinguishable for four reasons. First, the same cyber weapon can be used in both military operations and civilian network defense. On the military side, cyber weapons are designed to hold targets at risk, collect information, and defend networks. But similar and often identical capabilities are also used by civilian actors to defend their networks against attack or industrial espionage. Consider Nmap, an open-source network scanner that is used by attackers and defenders alike to identify vulnerabilities in networks.[5] This type of penetration testing is an effective way to shore up network defenses, but requires access to the latest exploits used by attackers.[6] Second, the development process often reveals little information about the intended use of the cyber weapon. For example, the private spyware industry develops cyber weapons for military and commercial customers across the globe.[7] Many cyber tools are useful for covert intelligence gathering. In the civilian context, however, these applications could also be employed with a user's awareness to protect them or the secure data on their device. Third, the deployment of cyber weapons for peaceful purposes can still be used to conduct military operations. Civilian penetration testing and surveillance software firms may be perceived as potential proxies or a metric of latent cyber power within a country. Fourth, many cyber weapons that emerge in a civilian context can be quickly converted for use in the military realm. In sum, the physical properties, development, and deployment of cyber weapons look similar in many commercial and military settings.

Integration: High (Military) / High (Civilian)

Cyber weapons evolved to comprise the integrity, availability, or confidentially of information on computers and networks, as well as the physical artifacts connected to such systems, such as industrial control devices in chemical manufacturing or uranium gas centrifuge plants. These capabilities became highly integrated within large swaths of the civilian economy and military-intelligence services for three reasons.[8]

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[5] Mario Silic and Andrea Back, "Information Security and Open Source Dual Use Security Software: Trust Paradox," in *Open Source Software: Quality Verification*, ed. Etiel Petrinja et al., IFIP Advances in Information and Communication Technology (Berlin, Heidelberg: Springer, 2013), 194–206, https://doi.org/10.1007/978-3-642-38928-3_14.
[6] C. C. Palmer, "Ethical Hacking," *IBM Systems Journal* 40, no. 3 (2001): 769–80, https://doi.org/10.1147/sj.403.0769.
[7] Dana Priest, Craig Timberg, and Souad Mekhennet, "Private Israeli Spyware Used to Hack Cellphones of Journalists, Activists Worldwide," *Washington Post*, https://www.washingtonpost.com/investigations/interactive/2021/nso-spyware-pegasus-cellphones/.
[8] For a similar assessment, see Jacquelyn Schneider, "The Capability/Vulnerability Paradox and Military Revolutions: Implications for Computing, Cyber, and the Onset of War," *Journal of Strategic Studies* 42, no. 6 (September 19, 2019): 841–63, https://doi.org/10.1080/01402390.2019.1627209.

First, a wide range of government and civilian actors rely on cyber weapons to either exploit or manage the security vulnerabilities intrinsic to IT systems. The pervasive use of cyber weapons in commercial settings is reflected by the growing market cap for penetration testing services, which was worth $1-2B in 2021 and is expected to reach $3-4B by 2025.[9] Penetration testing has been employed in most sectors of the economy, especially in those where security is paramount, such as the aerospace, defense, and financial industries.[10] National governments employ similar services, but also appear to use cyber weapons as multifunctional tools of data exfiltration (espionage) and attack (sabotage), including destruction or denial of physical assets and electronic services.[11] According to Herbert Lin, "the use of cyber weapons could be integrated into military operations in much the same way as kinetic weapons," where they "become just another weapon that military commanders might use."[12]

Second, the cost of developing cyber weapons varies with sophistication but effects can be achieved with modest means.[13] Some cyber weapons can also be modified and re-used with minimal cost. Once advanced cyber weapons are used or otherwise revealed to the public, the code can sometimes be modified and used by network attack and defense actors in commercial and military setting around the globe.

Third, cyber weapons exhibit strong spillover effects because they can open up new use opportunities. For example, efforts to protect the integrity of information against cyberattacks led to the development of new cryptographic techniques, such as blockchain for publicly distributed ledgers.[14]

Outcomes

Consideration but no agreement. States and nongovernmental actors have considered various ideas for limiting either the acquisition or use of cyber weapons. But no agreements were ever reached that would directly or explicitly forbid the development or deployment of cyber weapons in world politics.[15] For example, the *New York Times* reports that American and Russian military delegations met in 1996 to discuss whether cyber weapons could be banned. Afterwards, "the Russian government repeatedly introduced resolutions calling for cyberspace disarmament treaties before

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[9] “The Global Penetration Testing Market Size to Grow from USD 1.6 Billion in 2021 to USD 3.0 Billion by 2026, at a Compound Annual Growth Rate (CAGR) of 13.8% from 2021 to 2026,” accessed August 30, 2021, https://www.yahoo.com/now/global-penetration-testing-market-size-190400245.html.
[10] Chen Hao and Jean-Pierre Corriveau, “Security Testing and Compliance for Online Banking in Real-World,” *Lecture Notes in Engineering and Computer Science* 2174 (March 1, 2009).
[11] Thomas Rid, “Cyber War Will Not Take Place,” *Journal of Strategic Studies* 35, no. 1 (February 1, 2012): 5–32, https://doi.org/10.1080/01402390.2011.608939.
[12] Lin, “Governance of Information Technology and Cyber Weapons,” 118.
[13] John Markoff, “Before the Gunfire, Cyberattacks,” *The New York Times*, August 12, 2008, sec. Technology, https://www.nytimes.com/2008/08/13/technology/13cyber.html.
[14] Cindy Vestergaard, “Better than a floppy: The potential of distributed ledger technology for nuclear safeguards information management,” Stanley Center for Peace and Security, https://stanleycenter.org/wp-content/uploads/2019/09/NPAIa-BetterFloppyVestergaard1018.pdf.
[15] For a more detailed overview, see Lin, “Governance of Information Technology and Cyber Weapons,” 123–33.

the United Nations. The United States consistently opposed the idea."[16] Some efforts to curtail specific types of behavior with cyber weapons have gained more traction, but still fall short of actual arms control. The Budapest Convention on Cybercrime of 2001 was designed to reduce cybercrime among forty-seven nations. However, the Budapest Convention was not an international arms control agreement; it merely standardized domestic criminal law across signatory nations.[17] In 2009, the six member states of the Shanghai Cooperation Organization issued a joint statement expressing their opposition to "information wars," but did not agree to forgo any cyber weapons or cyberattacks. Similarly, Russia and China signed an agreement in 2015 to cooperate on information security, but the text of the document did not explicitly limit cyber weapons in any meaningful way.[18] The United States and China also reached an agreement in 2015 that was narrowly designed to reduce industrial espionage (Australia also signed a similar high-level agreement with China in 2017).[19] In March 2021, the United Nations achieved a consensus among all member states to regulate state-sponsored cyber-attacks, but these norms remain nonbinding and contain no verification measures.[20]

Theory Support: <u>Strong for H2</u>.

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[16] John Markoff and Andrew E. Kramer, "U.S. and Russia Differ on a Treaty for Cyberspace," *The New York Times*, June 27, 2009, sec. World, https://www.nytimes.com/2009/06/28/world/28cyber.html.
[17] Lin, "Governance of Information Technology and Cyber Weapons," 130–31.
[18] Lin, 131–32.
[19] "Trump's Erratic Style Could Undermine China's Agreement to Stop Hacking U.S. Businesses," *Los Angeles Times*, April 3, 2017, https://www.latimes.com/politics/la-fg-us-china-cyber-20170403-story.html; "High-Level Security Dialogue with China: Joint Statement," Australian Government Department of Foreign Affairs and Trade, https://www.dfat.gov.au/news/media/Pages/high-level-security-dialogue-with-china-joint-statement.
[20] "Russia, U.S. and Other Countries Reach New Agreement against Cyber Hacking, Even as Attacks Continue," *Washington Post*, accessed September 17, 2021, https://www.washingtonpost.com/national-security/russia-us-un-cyber-norms/2021/06/12/9b608cd4-866b-11eb-bfdf-4d36dab83a6d_story.html.

Drones

Technology Definition

We use the term ‘drone’ to denote aerial vehicles that navigate through the air via remotely controlled or autonomous flight systems.[1] Our definition focuses on unmanned aerial vehicles (UAVs) and excludes other types of unmanned and autonomous vehicles. We consider unmanned underwater vehicles (UUVs) to be the closest peaceful analogue to torpedo technology—see the Torpedoes case study. In addition, unmanned ground vehicles (UGVs) are also excluded because these platforms are essentially extensions of automobile or armored vehicle technologies. UAVs come in a variety of airframes with different configurations and propulsion systems. The technology is distinct in both form and function from traditional aircraft, so we follow others in treating it as separate category. However, we acknowledge that some scholars argue the line may become fuzzy between cruise missiles and some drones in the years ahead.[2]

Time Period Boundaries

Drone technology made its operational debut in 1982, when Israel used unmanned ariel vehicles (UAVs) to enhance battlefield effectiveness. In June 1982, Israel relied on UAVs to provide intelligence support against targets in Lebanon. During the initial phase of the conflict, UAVs enabled Israeli air and ground forces to destroy advanced surface-to-air missile batteries in the Bekaa Valley. This major defeat of modern air defense systems demonstrated the military potential for drone technology, which lead to significant research and development efforts over the next decade in Israel and the United States.[3] These efforts culminated in the first reliable long-range armed UAV in 1994—the General Atomics MQ-1 Predator. Other scholars use the introduction of the MQ-1 Predator in 1994 to mark the start of the modern drone era.[4] This alternative debut date does not change how we code the dual use technology attributes.

We break the case up into two time periods: (1) operational debut and development from 1982–2006; (2) commercial and military expansion from 2006–2020. Drone

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[1] For a similar definition, see Sarah E. Kreps, *Drones: What Everyone Needs to Know* (Oxford University Press, 2016).
[2] See, for example, Peter Singer quoted in Patrick Tucker, “Every Country Will Have Armed Drones Within 10 Years,” Defense One, May 6, 2014, https://www.defenseone.com/technology/2014/05/every-country-will-have-armed-drones-within-ten-years/83878/.
[3] See John F. Kreis, “Unmanned Aircraft in Israeli Air Operations,” *Air Power History* 37, no. 4 (1990): 46–50; Richard Whittle, *Predator: The Secret Origins of the Drone Revolution* (New York, NY: Henry Holt and Company, 2014).
[4] See, for example, Michael Horowitz, Joshua A Schwartz, and Matthew Fuhrmann, “Who’s Prone to Drone? A Global Time-Series Analysis of Armed Uninhabited Aerial Vehicle Proliferation,” *Conflict Management and Peace Science*, November 27, 2020, 0738894220966572, https://doi.org/10.1177/0738894220966572.

technology underwent a major change from high to low distinguishability in 2006 when the Federal Aviation Administration issued its first commercial license for UAVs. The level of integration within the civilian economy also shifted from low to high at this time (military integration remained high over time).

Drones, 1982–2006

Distinguishability: High

The military use of drone technology was highly distinguishable from civilian applications for four reasons. First, civilian drones were virtually nonexistent during this time. Hobbyists could remote pilot miniature aircraft with radio controls. But the main drone programs were all focused on delivering surveillance and attack platforms to military and intelligence service users. This led to the genesis of UAVs with physical characteristics that indicated military use, such as the long-range, sustained loiter capacity, and payload delivery capabilities of the MQ-1 Predator. Second, military drones were developed in dedicated military programs that diverged from civilian aerospace applications. Massive development barriers also made it prohibitively costly and difficult for most nonmilitary users to leverage the technology. Third, the deployment pattern for military drones made it easy to divine use. For example, advanced UAV platforms such as the Predator or Reaper depended on extensive logistical support to operate in the field, such as forward defense bases and datalinks.[5] This set military UAVs apart from any comparable civilian technology that lacked these extensive resources and features. Fourth, civilian drones could not be readily converted into the military platforms at the time. Although it was possible to equip a radio-controlled aircraft with a crude explosive, the operational effectiveness of this weapon would be in doubt.

Integration: High (Military) / Low (Civilian)

Drones became highly integrated within military enterprises during this period because the technology was used to perform a wide range of military and intelligence missions. UAVs initially carried out surveillance, reconnaissance, and targeting operations. But this mission set expanded when the United States deployed Predators armed with Hellfire missiles in Afghanistan after the September 11 attacks. Drones offered unique operational advantages because they could sustain persistent flight patterns over targets.[6] This made them well suited to supplement other military forces in a variety of

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[5] Andrea Gilli and Mauro Gilli, "The Diffusion of Drone Warfare? Industrial, Organizational, and Infrastructural Constraints," *Security Studies* 25, no. 1 (January 2, 2016): 50–84, https://doi.org/10.1080/09636412.2016.1134189.
[6] Michael C. Horowitz, Sarah E. Kreps, and Matthew Fuhrmann, "Separating Fact from Fiction in the Debate over Drone Proliferation," *International Security* 41, no. 2 (October 2016): 21, https://doi.org/10.1162/ISEC_a_00257.

contexts, especially counterterrorism operations in uncontested airspace. Drones were expensive to develop and operate during this period.[7] But the relative costs were modest when considered within the context of aerospace technology, which tended to be quite high in the military domain. The development of advanced drones also spilled over into more general robotics technology, which started to make major leaps forward in the 2000s. However, there were almost no uses for the technology within the civilian economy. One scholar argues that "drones were almost exclusively the province of militaries."[8] The technology remained too sophisticated and expensive for commercial use.

Outcomes

Agreement with unilateral collection methods. Drones were included in a key multilateral export control regime. In 1987, states agreed to limit the export of UAVs with specific range and payload features (300km/500kg) under the new Missile Technology Control Regime.[9] The Wassenaar Arrangement's Dual-Use List also adopted similar restrictions in 1996. These agreements coordinated export controls and improved information sharing. States relied on their own unilateral collection methods to verify compliance.

Theory Support: Strong for H4. This outcome lends strong support for our theory because states used unilateral means to monitor compliance.

Drones, 2006–2020

Distinguishability: Low

In 2006, the Federal Aviation Administration issued its first commercial license for UAVs. This was a watershed moment in the evolution of drone technology, as it helped spur the introduction of peaceful UAVs. Of course, there were still some high-end drones that remained almost exclusively military. However, many military drones became more indistinguishable from their burgeoning civilian counterparts after 2006 for four reasons. First, the physical characteristics of many civilian and military drones started to look similar. Advances in robotics and computing led to greater diversity in drone technology, such as smaller UAVs and better communication and control

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[7] Andrea Gilli and Mauro Gilli, "Why China Has Not Caught Up Yet: Military-Technological Superiority and the Limits of Imitation, Reverse Engineering, and Cyber Espionage," *International Security* 43, no. 3 (February 2019): 141–89, https://doi.org/10.1162/isec_a_00337.
[8] Gretchen West, "Drone On: The Sky's the Limit-If the FAA Will Get Out of the Way," *Foreign Affairs*, June 2015, 90.
[9] Deborah A. Ozga, "A Chronology of the Missile Technology Control Regime," *The Nonproliferation Review* (Winter 1994), 66–93.

systems.[10] With a few modifications, the same drone could be used to assist with disaster relief efforts or deliver munitions on the battlefield.[11] Second, the civilian development of drone technology started to overlap with the military sector. Commercial investment further diversified the spectrum of drone capabilities, from new miniature units to improvements in large fixed-wing UAVs.[12] Military users could leverage these innovations to field more advanced weapon systems. Third, many civilian and military drones began to follow similar deployment patterns and carried out analogous tasks. To be sure, some advanced military UAV platforms continued to require extensive support structures and unique doctrinal employment choices. But the use of drones in nonmilitary security started to blur the line, Schulzke argues, because “the machines involved are often similar, or even identical, to those used by militaries and perform comparable roles.” He also notes that, “the same basic operations, such as tracking, patrolling, and delivering payloads, are undertaken across civilian and military roles.”[13] Fourth, military drones started to be converted for civilian use, often with simple changes. According to Schulzke, “the transferability of completed drones across civilian and military functions with comparatively few modifications … means that drone hardware and operational knowledge can develop in nonmilitary settings and that technologies can be transferred between military and civilian domains as expediency requires.”[14] In 2006, for example, US federal agencies transformed the MQ-1 Predator into a nonmilitary UAV for domestic surveillance and disaster relief operations by removing its weapons platforms and advanced intelligence sensors. As a result, the distinguishability of drones decreased from high to low during this time.

Integration: High (Military) / High (Civilian)

Drones exhibited a high degree of integration within military enterprises and especially within the civilian economy after 2006 for three reasons. First, the introduction of new UAV systems further expanded the range and variety of military missions. Whereas drones were previously used in counterterrorism or other operations over uncontested airspace, the proliferation of UAV technology opened new use opportunities. For example, states began to use drones to monitor and defend disputed territory or carry out attacks in contested airspace. More important, drones started to perform many different tasks in a diverse array of commercial industries, from construction and

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[10] On the global diffusion of basic and advanced drone capabilities, see Matthew Fuhrmann and Michael C. Horowitz, “Droning On: Explaining the Proliferation of Unmanned Aerial Vehicles,” *International Organization* 71, no. 2 (ed 2017): 397–418, https://doi.org/10.1017/S0020818317000121.
[11] Marcus Schulzke, “Drone Proliferation and the Challenge of Regulating Dual-Use Technologies,” *International Studies Review* 21, no. 3 (September 1, 2019): 502, https://doi.org/10.1093/isr/viy047.
[12] For an overview of different UAV capabilities, see “Nonproliferation: Agencies Could Improve Information Sharing and End-Use Monitoring on Unmanned Aerial Vehicle Exports,” Report to the Ranking Member, Subcommittee on National Security, Homeland Defense, and Foreign Operations, Committee on Oversight and Government Reform, House of Representatives (Washington, DC: U.S. Government Accountability Office, July 2012), https://www.gao.gov/assets/gao-12-536.pdf.
[13] Schulzke, “Drone Proliferation,” 502.
[14] Schulzke, 502.

agriculture to logistics and data collection. Reflective of this trend, the FAA had issued over 1.1 million commercial licenses for UAVs to operate in the United States by 2019. Second, many UAVs became much cheaper to produce and easier to operate. The most cutting-edge military drones remained expensive and complex platforms that still needed to be operated by specially trained pilots.[15] But, according to *The Economist*, intense competition in the consumer and industrial markets for smaller unarmed drones "made the machines much cheaper, more reliable and more capable than they were just a few years ago."[16] Military enterprises were able to leverage commercial innovations to lower development costs on drones and subcomponent technologies.[17] Indeed, one scholar found that the drone market had become "vast, heterogeneous, and conducive to civil-military technology sharing."[18] Third, drones continued to generate strong spillover effects. The development of UAV systems was intimately linked to more general breakthroughs in robotics driven by commercial enterprises during this era.[19]

Outcomes

Consideration but no new agreements. States considered strengthening arms control institutions but reached no new agreements to limit or ban UAV systems during this time. As a result, the existing export control limitations covered a shrinking range of drone technology. Indeed, most drones available on the global market became unregulated—only 7 percent of all UAV systems were subject to MTCR controls in 2012, for example.[20] In 2017, MTCR members rebuffed most proposals from the United States to further relax UAV restrictions. In 2020, Washington unilaterally downgraded some of its advanced UAVs out of the most restrictive MTCR category, eroding the regime's controls.[21] Proposals to limit other categories of drones failed to garner traction.

Theory Support: Strong for H2. The absence of new agreements amid the steady erosion in export controls over drones aligns with what we would expect to see for H2.

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[15] Bradley T. Hoagland, "Manning the Next Unmanned Air Force: Developing RPA Pilots of the Future" (Washington, DC: Brookings, August 2013), https://www.brookings.edu/research/manning-the-next-unmanned-air-force-developing-rpa-pilots-of-the-future/. See also Gilli and Gilli, "Why China Has Not Caught Up Yet."
[16] "Taking Flight: Civilian Drones," The Economist, June 8, 2017, https://www.economist.com/technology-quarterly/2017-06-08/civilian-drones.
[17] Rachel Stohl, "UAV Export Controls and Regulatory Challenges: Working Group Report" (Washington, DC: Stimson Center, October 13, 2015), https://www.stimson.org/wp-content/files/file-attachments/ECRC%20Working%20Group%20Report.pdf.
[18] Schulzke, "Drone Proliferation," 498.
[19] Horowitz, Kreps, and Fuhrmann, "Separating Fact from Fiction in the Debate over Drone Proliferation," 14.
[20] "Nonproliferation," 20–21.
[21] Daryl G. Kimball, "U.S. Reinterprets MTCR Rules," Arms Control Association, September 2020, https://www.armscontrol.org/act/2020-09/news/us-reinterprets-mtcr-rules.

Firearms

Technology Definition

Modern firearm technology is best defined around the rifle, which is a hand-held, shoulder-fired weapon with a spiral groove, or "rifling," carved along the length of the barrel's interior. When this type of firearm is discharged, the rifling grips and imparts a spin upon the projectile as it travels down the barrel, thus greatly improving its range and accuracy. Early firearms, commonly known as muskets, were built with a smooth-bored barrel that did not impart any sort of spin on the projectile it discharged. This made muskets highly distinguishable as a firearm technology used primarily for military purposes from the 11th to the 15th centuries in China and Europe. We exclude smooth-bored barrel muskets from the analysis because the rifling technique developed in the early 16th century is commonly accepted by historians as the genesis of modern firearm technology.[1] We also omit discussions of smaller, hand-held machine guns and automatic rifles that emerged throughout the 20th century.

Time Period Boundaries

Historians break rifle technology into two periods: (1) early debut from 1520–1840; (2) modern maturation and global diffusion from 1840–2020. Rifle technology debuted in 1520 as a specialized weapon for civilians and select military forces. Most historians agree that the spiral grooved gun barrel was invented in 1520 by Nuremberg based inventor, Augustus Kotter.[2] But it took three centuries for the rifle to mature. The key break in dual use characteristics began in 1840 when technological innovations made rifles increasingly distinguishable and useful for performing a range of military tasks. We therefore break the rifle case study up into two time periods (1520–1840; 1840–2020).

Firearms [Rifles], 1520–1840

Distinguishability: <u>Low</u>

Late-15th century gunsmiths in the Alpine regions of southern Germany and northern Switzerland pioneered the rifling technique to correct for the greatest flaw in early firearm technology: the smooth-bored barrels in muskets that made them only useful for firing inaccurate volleys over short distances. Despite this major leap forward, rifles were mostly used in civilian pursuits for three centuries after their invention, notably

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[1] For an excellent account of early firearms in China and Europe, see Tonio Andrade, *The Gunpowder Age: China, Military Innovation, and the Rise of the West in World History* (Princeton, NJ: Princeton University Press, 2016); see also Kenneth Chase, *Firearms: A Global History to 1800* (Cambridge, UK: Cambridge University Press, 2003); Wayne E. Lee, *Waging War: Conflict, Culture, and Innovation in World History* (New York: Oxford University Press, 2016), 366.

[2] See Henry J. Kauffman, *The Pennsylvania-Kentucky Rifle* (Harrisburg, PA: Stackpole Co., 1960).

hunting, target-shooting, and self-defense (especially in rural frontier zones).[3] Small groups of highly-trained soldiers used rifles on a limited basis for special missions where range and accuracy were paramount. But the slow reloading speed and expense involved with manufacturing rifles limited their military utility because infantry tactics in the early-modern era relied on massed volleys of musket fire coupled with a bayonet charge. As a result, there was little distinction between rifles used for civilian or military purposes during this period. In both cases, they were cumbersome and slow-firing yet relatively accurate weapons that offered significant, but certainly not precise, advantages over their smoothbore counterparts.

Integration: Low (Military) / Low (Civilian)

Rifles remained isolated to niche civilian markets and special military operations until the mid-19th century for two reasons. First, infantry tactics in this era were not conducive to the rifle. In the 18th century, infantrymen utilized massed volleys of musket fire delivered at close range to soften an opposing body of soldiers before driving the attack home with a bayonet charge.[4] Unlike the smoothbore, with which the handler used a ramrod to push a loose-fitting ball down the barrel, a rifleman used larger bullets that could grip the rifling and had to ram each one down the barrel with a mallet and spike. Reloading after each shot took much longer, which was a weakness in an era where speedy reloading, collective discipline, and shock were more decisive than individual precision.[5] Second, rifles were time-consuming and expensive to manufacture at scale. States resisted arming their soldiers with rifles for economic reasons. The rifle-boring process in the early modern era was a slow, "skilled-labor-intensive, expensive process: carving the spiraled groove required a specialized machine. Ensuring that the barrel was absolutely straight needed a highly-experienced craftsman who commanded among the highest wages then available."[6] Rifles remained a special commodity in

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[3] Hunters in the Alps soon learned they could accurately fire on bears, stags, and other big game from as far as 200 yards away. The weapon spread across Europe and found additional civilian uses, notably becoming a common tool in target-shooting competitions by 1580. A century later, German immigrants brought rifle technology to North America, where frontiersmen found the weapon to be an extremely potent tool for hunting and self-defense in the continent's rugged interior. See Alexander Rose, *American Rifle: A Biography* (New York: Delta Trade, 2009), 14-5.

[4] Until the late-17th century, the pike was the infantryman's primary weapon for hand-to-hand fighting against cavalry and other infantry. The firearm was thus not the primary infantry weapon until the socket bayonet's invention and proliferation around the turn of the eighteenth century. See William H. McNeill, *The Pursuit of Power: Technology, Armed Force, and Society since A.D. 1000* (Chicago: The University of Chicago Press, 1984), 94-7, 123-9, 134-6, 141, 173.

[5] Rose provides a very brief synopsis of early modern infantry combat in *American Rifle,* 24-5. For more detailed discussions, see Christopher Duffy, *The Military Experience in the Age of Reason* (New York: Routledge & Kegan Paul, 1987), 200-14; John A. Lynn. "The Battle Culture of Forbearance, 1660-1789," in *Warfare and Culture in World History*, ed. Wayne E. Lee, 89-114 (New York: New York University Press, 2011); Dennis Showalter, *Frederick the Great: A Military History* (London: Frontline Books, 2012), particularly 65-8; Additionally, David Blackmore provides an exhaustive study of British fire tactics in *Destructive and Formidable: British Infantry Firepower 1642-1765* (London: Frontline Books).

[6] Rose, *American Rifle,* 15.

civilian and military spheres for over three centuries, used only by landholding elites, frontiersmen, and select soldiers.

Outcomes

No agreements. Given the limited utility of rifles during this period, it is not surprising that they were not included in arms control agreements until the technology matured after 1840. But this makes it difficult to assess the role that the dual use nature of firearms played in the absence of cooperation. The case therefore offers neutral support, neither confirming nor disconfirming our expectations for H3.

Theory Support: Neutral for H3. Though the outcome is not inconsistent with H3, the reasons for no arms control is likely more due to lack of benefit from a low use/low impact capability rather than from the difficulty of distinguishing civilian vs. military uses. We therefore code the outcome as neutral in theory support.

Firearms [Rifles], 1840–2020

Distinguishability: High

Three major innovations in rifle technology emerged after the 1840s that made individual, handheld weaponry increasingly distinguishable as a military-only use technology. First, advances in manufacturing with modern machine tools made it feasible to equip entire armies with mass produced rifles. In the early-19th century, inventors and craftsmen on both sides of the Atlantic started to master new techniques in machining and shaping metal, as well as the production of machine-made, interchangeable parts. By the 1850s, advances in machine tools had so increased production capacity that it was feasible, and affordable, for industrialized states to refit their armies and to arm their infantry exclusively with rifles. This weapons development process diverged from the traditional methods used to develop rifles in small quantities for civilian applications.[7] Second, in 1847, French army officer Claude-Étienne Minié

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[7] However, the underlying manufacturing technology soon spread into the civilian sphere, where is became increasingly indistinguishable, see the Manufacturing [Machine Tools] case study. On link between machine tools and firearm production in the United States, see Merritt Roe Smith, *Harpers Ferry Armory and the New Technology: The Challenge of Change* (Ithaca, NY: Cornell University Press, 1980). On the mass production of firearms, see Wayne E. Lee, *Waging War: Conflict, Culture, and Innovation in World History* (New York: Oxford University Press, 2016, 376-7; Alexander Rose, *American Rifle: A Biography* (New York: Delta Trade, 2009), 69-72, 79-81, 89-94, 232-7; for a discussion on production innovations in Europe, see William H. McNeill, *The Pursuit of Power: Technology, Armed Force, and Society since A.D. 1000* (Chicago: The University of Chicago Press, 1984), 232-7.
[7] David A. Hounshell, *From the American System to Mass Production, 1800-1932: The Development of Manufacturing Technology in the United States* (Baltimore, MD: The Johns Hopkins University Press, 1985), 3–5.

invented a conoidal bullet with a hollow base. This “Minié ball” slid loosely down the barrel like its spherical predecessor yet, when fired, gas pushed into the base expanded the bullet, thus gripping the rifling, imparting a spin on the projectile, and greatly increasing its range and accuracy.[8] Minié’s invention thus offered a cheap and quick solution to the rifle’s slow and burdensome reloading process. This innovation created new military deployment opportunities for rifles. Third, the breech-loading rifle, with which the operator loaded the bullet directly into the chamber rather than ramming it down the muzzle, increased the rifle’s battlefield effectiveness and versatility. The breech-loader could be reloaded much faster than the muzzle-loader, and its smaller size and simplified reloading process meant soldiers could also load and fire while kneeling behind cover and in the prone. The development of smaller-caliber but higher-powered (nitrocellulose) bullets made it possible for a soldier to carry more ammunition than ever before. Increasingly efficient feeding and ejection mechanisms followed soon after, as did internal and external clip-fed designs, all of which greatly increased the individual rifle’s firing capacity.[9] Each innovation was designed to make rifles more feasible for large scale military use and more effective on the battlefield. While one could argue that civilian rifleman also benefited from these improvements, most were superfluous to noncombatant purposes. In the example of hunting, the ability to engage a target from unprecedented distances had its advantages, but the ability to fire increasingly higher numbers of projectiles in shorter periods of time did not. Rifle technology came to predominately serve clear military purposes by the 19th century’s latter half.

Integration: <u>High</u> (Military) / <u>Low</u> (Civilian)

The technological breakthroughs of the industrial revolution in the mid-19th century transformed rifles into a highly integrated weapon for two reasons. First, as noted in the distinguishability section, improvements in projectile and firing capacity technologies expanded rifle's range of uses in modern warfare. Second, rapid increases in production capacity made it possible to equip entire armies with rifles. The Minié bullet, nitrocellulose, and breech-loader were significant military innovations, but they did not spur the widespread use of rifles on their own. The timing of these breakthroughs was just as important as the new technologies. They all occurred around the same time that inventors and craftsmen on both sides of the Atlantic were beginning to master new techniques in machining and shaping metal, as well as the production of machine-made, interchangeable parts. By the 1850s, advances in machine tools and manufacturing made it feasible, and affordable, for industrialized states to refit their armies and to arm their infantry exclusively with rifles.[10] The widespread adoption of

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[8] Lee, *Waging War,* 366-7; Rose, *American Rifle,* 111-3; McNeill, *Pursuit of Power,* 231-2.
[9] Lee, *Waging War,* 379; Geoffrey Wawro, *Warfare and Society in Europe 1792-1914* (New York: Routledge, 2000), 136-9.
[10] Lee, *Waging War,* 376-7. For a more detailed discussion on interchangeable parts and production innovations in the United States, see Rose, *American Rifle,* 69-72, 79-81, 89-94, 232-7; for a discussion on production innovations in Europe, see McNeill, *Pursuit of Power,* 232-7.

rifled firearms made an immediate impact on European and North American battlefields in the late-19th and early-20th centuries.[11] Soldiers could now wreak devastation on their foes from greater distances and with a volume and accuracy that was inconceivable just a few decades before. As a result, rifles became universally used by combatants around the world throughout the 20th century. However, the range and variety of uses for rifles in the civilian context remained limited to sports activities and personal defense.

Outcomes

Agreements with unilateral collection methods. Arms control agreements over firearms tend to come in two main forms: (1) in the aftermath of armed conflict as part of a peace treaty or armistice agreement; (2) as part of efforts to strengthen export controls. These agreements all lack verification measures, with the sole exception of peace treaties imposed on defeated nations, notably the Treaty of Versailles. The Convention for the Control of the Trade in Arms and Ammunition (1919) regulated the export of firearms and other conventional weaponry in the wake of the First World War, but contained no verification measures outside of the intrusive inspections imposed on Germany in the Treaty of Versailles (1919). After the Arab-Israeli war, the Israel-Egypt Armistice Agreement (1949) set limits on the quantity of firearms that could be maintained by Israeli forces in specific geographic zones. Although the United Nations supervised the overall armistice agreement, the treaty included no verification measures for ensuring compliance with conventional arms limitations. Several regional and international organizations have reached agreements to regulate the export of firearms. The Inter-American Convention Against the Illicit Manufacturing of and Trafficking in Firearms, Ammunition, Explosives, and Other Related Materials (1997) established regional standards for the production and trade of firearms, but only facilitated information sharing among member states. In a similar vein, the European Union took several steps to limit the export of firearms to conflict zones, such as its Joint Action (1998) and Strategy (2005) Concerning the Spread of Small Arms and Light Weapons. Other states adopted similar export restrictions, such as the Nairobi Protocol and the ECOWAS Convention. These efforts all established mechanisms for better information sharing among member states. At the international level, the United Nations Conventional against Transnational Organized Crime (2000) and specially the Firearms

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[11] The Crimean War (1853-56), the first major armed conflict in the mid-nineteenth century, pitted the rifle-armed armies of Britain and France against Russian troops still using smoothbores. The former's advantages over the latter were unmistakable. See McNeill, *Pursuit of Power,* 225-30, 233-8, 258, 286; Wawro, *Warfare and Society in Europe*, 55-60; Orlando Figes. *The Crimean War* (New York: Metropolitan Books, 2010), particularly 210, 214-7, 254, 260, 265. For discussions on the American Civil War, the first conflict in which there was relative parity among infantry firearms, see Earl J. Hess. *The Rifle Musket and Civil War Combat* (Lawrence: University Press of Kansas, 2008); Joseph T. Glatthaar, "Battlefield Tactics," in *Writing the Civil War: The Quest to Understand*, ed. James M. McPherson and William J. Cooper, Jr. (Columbia, SC: University of South Carolina Press, 1998), 60-80; Paddy Griffith. *Battle Tactics of the Civil War*, 2nd ed. (Ramsbury, UK: Crowood Press, 2014).

Protocol (2001) sought to control and regulate the international flow of licit and illicit small arms flows around the world, but both resolutions lacked verification mechanisms, relying instead on voluntary information exchanges.

Theory Support: Strong for H4. These outcomes all lend strong support for our theory because states used unilateral means to monitor compliance.

Hypersonic Vehicles

Technology Definition

Hypersonic technology refers to vehicles with the capacity to travel at least five times the speed of sound (Mach 5). There are five distinct subcategories:

(1) Hypersonic glide vehicles (HGVs) are missile re-entry vehicles that utilize a ballistic trajectory to attain hypersonic speeds and then, when they separate from the rocket booster, travel unpowered (i.e., glides) with maneuverability to its target. The defining feature of HGVs is their maneuverability upon reentry from a low altitude flight path, not necessarily their hypersonic speed. This maneuverability gives HGVs a novel and somewhat unpredictable trajectory, making them difficult to be intercepted by existing missile defense systems.[1] We consider this weapon system to be *the main military application of hypersonic technology* because it has reached an operational stage of development.

(2) Modern spacecraft operate in the hypersonic regime with some degree of maneuverability upon reentry into the earth's atmosphere. The most notable example is the US Space Shuttle, which executed special hypersonic maneuvers to decrease speed during reentry.[2] Earlier reentry capsules such as Apollo and Soyuz travelled at hypersonic speeds but lacked the maneuverability of later spaceplanes. *We treat spacecraft as the primary non-weapons use for hypersonic technology.* However, both the Space Shuttle and especially the more recent Boeing X-37 can be operated for military purposes.[3] Note: *<u>We consider spacecraft to be part of the Space technology category as well because it enters orbital planes</u>. Spacecraft share the same low distinguishability features in both categories; but other space technology, notably orbital satellites, exhibits higher integration over time.* Satellites also orbit the earth at high speed but are not subjected to the hypersonic regime in the vacuum of space. We therefore exclude satellites and treat this technology as a distinct category.

(3) Some experimental aircraft travel at hypersonic speeds. In 1959, NASA successfully flew the first such hypersonic test vehicle named the X-15.[4] This early demonstration led to decades of civilian research on hypersonic flight as a way to rapidly transport passengers and cargo. Despite the allure of hypersonic airliners, the technology has never progressed beyond early research and development efforts. *We include this potential peaceful application because*

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[1] Kelley M. Sayler, "Hypersonic Weapons: Background and Issues for Congress," Congressional Research Service Report, No. R45811, 25 August, 2021, https://sgp.fas.org/crs/weapons/R45811.pdf.

[2] Tom Benson, "Speed Regimes: Hypersonic Re-Entry—Space Shuttle," National Aeronautics and Space Administration, 7 May 2021, https://www.grc.nasa.gov/www/BGH/hihyper.html.

[3] "X-37B Orbital Test Vehicle," Air Force, accessed January 7, 2022, https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104539/x-37b-orbital-test-vehicle/.

[4] William E. Burrows, *This New Ocean: The Story of the First Space Age* (New York, NY: Modern Library, 1999), 249–51.

many nations pursue hypersonic technology under the guise of reaping such commercial benefits.[5]

(4) Hypersonic cruise missiles (HCMs) are powered by advanced "scramjet" engines to reach a target at high speeds. *We exclude this potential weapon because the technology is still at a very early stage of development.*

(5) Reentry vehicles on intercontinental ballistic missiles travel through the atmosphere at hypersonic speeds, sometimes with maneuverability as well. *We exclude these reentry vehicles* because they follow a distinct high altitude flight path and are better considered to be part of the ballistic missile technology category (see Rockets).

Time Period Boundaries

Although maneuverable hypersonic aircraft emerged in 1959 with the X-15, the operational debut date for the technology came later with the first manned launch of the *Columbia* Space Shuttle on April 12, 1981.[6] As a weapons platform, the United States began exploring the concept of HGVs in the early 1970s, leading to the first successful flight test in 1985.[7] The weapons technology languished until the US military started to develop new missile systems in the early 2000s as part of the Conventional Prompt Global Strike (CPGS) program. The US government prioritized funding for HGV technology after 2003, with flight tests in 2010, 2011, and 2017. Russia and China also initiated HGV development programs during this time.[8] We treat hypersonic vehicles as a single case study because the technology has not yet exhibited variation in either dual use attribute.

Hypersonic Vehicles, 1981–2020

Distinguishability: Low

Hypersonic technology exhibits low distinguishability for four reasons. First, HGVs and spacecraft share some physical characteristics unique to operating maneuverable vehicles in the hypersonic flight regime. Advanced thermal protection systems are required for both types of vehicles to survive the intense heating environment associated with traveling beyond Mach 5 in the atmosphere. However, HGVs tend to be more compact in size and experience higher aerodynamic heating relative to larger

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[5] Richard Speier et al., *Hypersonic Missile Nonproliferation: Hindering the Spread of a New Class of Weapons* (RAND Corporation, 2017), https://doi.org/10.7249/RR2137.
[6] Burrows, *This New Ocean*, 523.
[7] George Leuenberger, "Hypersonics Overview," *Sandia National Laboratories,* 2019, https://www.osti.gov/servlets/purl/1645511.
[8] Sayler, "Hypersonic Weapons"; James M. Acton, "Silver Bullet? Asking the Right Questions about Conventional Prompt Global Strike," Carnegie Endowment for International Peace, Brief, September 2013, https://carnegieendowment.org/files/Brief-Acton.pdf.

spacecraft with slower and more limited reentry trajectories, such as the Space Shuttle.[9] But this means that HGVs are quite like smaller (often unmanned) rocket-launched spacecraft capable of greater maneuverability upon reentry, such as the experimental space plane China tested in September 2020.[10] As Jeffrey Lewis quipped, HGVs are essentially "the same concept, except you put a nuclear weapon on the glider and don't bother with a landing gear."[11] The flight path can also overlap at specific stages, notably launch and reentry. The main difference is that spacecraft are often launched into orbit before entering the hypersonic regime, whereas most HGVs are designed to avoid orbital flight paths in favor of ascending from a lower altitude apogee to the target. Of course, a hypersonic weapon could be sent into orbit before making its descent, which would further blur the line between spacecraft and military missile systems.

Second, the military development of HGVs overlaps with civilian and non-weapons research on hypersonic spacecraft and airliners. Serial production of dedicated HGV weapon systems requires a special defense industry base.[12] But the military development pathway need not significantly diverge from civilian research at earlier stages. Indeed, many hypersonic test facilities are housed at university research centers where scientists study the unique speed, pressure, and heating conditions experienced by these vehicles. Special metals and ceramics can also be developed for use in civilian spacecraft or experimental airliners. Military programs can leverage these innovations to improve HGVs and the underlying production process.[13] The development overlap also means that many countries with ostensibly civilian hypersonic research programs could use this knowledge to jumpstart work on military HGVs.[14]

Third, the current stage of deployment for HGVs is difficult to separate from more benign spacecraft operations. The main problem is that most HGVs are undergoing a battery of tests. Aside from Russia's claim to have deployed its Avangard HGV on the SS-19 Stiletto ICBM, there are no large deployments of hypersonic weapons in the

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[9] Speier et al., *Hypersonic Missile Nonproliferation*, 101–2; Steven J. Dick, "Historical Background—What Were the Shuttle's Goals and Possible Configurations?," National Aeronautics and Space Administration, April 5, 2001, https://history.nasa.gov/sts1/pages/scota.html.
[10] Geoff Brumfiel, "New Chinese Space Plane Landed At Mysterious Air Base, Evidence Suggests," *NPR*, September 9, 2020, sec. Science, https://www.npr.org/2020/09/09/911113352/new-chinese-space-plane-landed-at-mysterious-air-base-evidence-suggests; Mark Zastrow, "How Does China's Hypersonic Glide Vehicle Work?," Astronomy Magazine, November 4, 2021, https://astronomy.com/news/2021/11/how-does-chinas-hypersonic-glide-vehicle-work.
[11] Jeffrey Lewis on Twitter on October 16, 2021, https://twitter.com/ArmsControlWonk/status/1449470160591413256.
[12] Aaron Mehta, "Pentagon Launches Hypersonic Industrial Base Study," Defense News, March 2, 2020, https://www.defensenews.com/pentagon/2020/03/02/pentagon-launches-hypersonic-industrial-base-study/; Colin Clark, "Hypersonics: Lockheed Says Supply Chain Is 'The Test,'" Breaking Defense, October 14, 2019, https://breakingdefense.com/2019/10/hypersonics-lockheed-says-supply-chain-is-the-test/.
[13] A U.S. Department of Defense official made this development strategy explicit: "We're especially interested in leveraging parts of the university community, the nontraditional layers — the folks who haven't done the basic high-speed fluid mechanics who can bring other capabilities to bear, [like] guidance, navigation and control, material development, systems engineering … We think it's important not only for development concepts but obviously to make the workforce available in industry, as well as in our government laboratories," quoted in Mehta, "Pentagon Launches Hypersonic Industrial Base Study."
[14] Speier et al., *Hypersonic Missile Nonproliferation*, xii, 106–7.

open-source.[15] But there are many tests of these weapons. Some involve the clear use of military platforms. For example, China has tested a ballistic missile specifically designed to launch HGV weapons; the US Department of Defense has conducted flight tests of its Common-Hypersonic Glide Body to be paired with land and sea launch missile systems.[16] But other tests blur the line between spacecraft launch and HGV deployment. In 2021, the Chinese Foreign Ministry claimed the launch of a hypersonic vehicle into orbit was not a missile test, but rather "a routine space vehicle test to verify the technology of repeated use of a space vehicle."[17] The similarity between spacecraft and some HGV tests made this claim hard to verify. “Because tests of space planes and some orbital weapons could be indistinguishable," James Acton concluded, "determining China’s intentions is difficult. In fact, it is even possible that China tested a technology demonstrator with multiple potential applications."[18]

However, it is probable that HGVs could follow a deployment pattern distinct from rocket-launched spacecraft in the future. The United States, Russia, and China have all announced plans to field hypersonic weapons that can be launched from air, sea, or land.[19] There is little confusion between space launch centers and a hypersonic glide vehicle atop a rocket on destroyer or ground launch platform. Spacecraft are often launched on different rockets. The X-37, for example, uses aboveground Atlas V or Falcon 9 launch systems to reach orbit.[20] By contrast, deployment of hypersonic weapons on military missile systems would be quite different from typical space launch operations. This is a key attribute to track in the years ahead, as it could lead to change in the distinguishability of hypersonic vehicle technology.

Fourth, modern spacecraft could be converted into weapon systems with some degree of maneuverability in the hypersonic realm. During the Cold War, for instance, some Soviet analysts feared that the US Space Shuttle might be used to drop a nuclear weapon on Moscow (even though the payload bay was mounted on top of the spacecraft and could not be opened during reentry).[21] However, the relatively slower

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[15] Andrew Osborn, “Russia Says It Has Deployed First Hypersonic Nuclear-Capable Missiles,” *Reuters*, December 27, 2019, sec. World News, https://www.reuters.com/article/uk-russia-nuclear-missiles-idUKKBN1YV191; “Russia Demonstrates Avangard Hypersonic Missile System to US,” TASS, November 26, 2019, https://tass.com/defense/1092885.
[16] Ankit Panda, “Introducing the DF-17: China’s Newly Tested Ballistic Missile Armed with a Hypersonic Glide Vehicle,” The National Interest, December 28, 2017, https://thediplomat.com/2017/12/introducing-the-df-17-chinas-newly-tested-ballistic-missile-armed-with-a-hypersonic-glide-vehicle; Jen Judson, “Next Flight Test of Hypersonic Glide Body Expected by Year’s End,” Defense News, August 11, 2021, https://www.defensenews.com/digital-show-dailies/smd/2021/08/11/next-flight-test-of-hypersonic-glide-body-expected-by-years-end/.
[17] Quoted in “‘Hypersonic’ Object Put Into Orbit Was Space Vehicle, China Claims,” Bloomberg, October 18, 2021, https://www.bloomberg.com/news/articles/2021-10-18/china-says-hypersonic-object-put-into-orbit-was-space-vehicle.
[18] James M. Acton, “China’s Tests Are No Sputnik Moment,” Carnegie Endowment for International Peace, October 21, 2021, https://carnegieendowment.org/2021/10/21/china-s-tests-are-no-sputnik-moment-pub-85625.
[19] For an overview, see Sayler, “Hypersonic Weapons.”
[20] “X-37B Orbital Test Vehicle.”
[21] Bart Hendrickx and Dwayne A. Day, “Target Moscow: Soviet Suspicions about the Military Uses of the American Space Shuttle,” The Space Review, January 27, 2020, https://www.thespacereview.com/article/3873/1.

rate of descent for spacecraft would make them more vulnerable to missile defenses upon detection, thereby neutralizing one key advantage offered by faster and more maneuverable HGVs.

Integration: <u>Low</u> (Military) / <u>Low</u> (Civilian)

Hypersonic vehicle technology exhibits low integration within both military enterprises and the civilian economy, albeit for different reasons. On the military front, the range and variety of uses for hypersonic weapons remains uncertain. The marginal costs and the spillover effects of military HGVs are difficult to estimate at this stage. Nations have been focused on testing operational platforms rather than articulating mission roles for the technology. In the United States, for example, James Acton points out that the "Department of Defense has not yet made any doctrinal decisions about the missions for which Conventional Prompt Global Strike (CPGS) weapons might be acquired."[22] However, Acton notes that HGVs are envisaged as a multipurpose weapon that could "counter antisatellite weapons or sophisticated defensive capabilities; deny a new proliferator the ability to employ its nuclear arsenal; and kill high-value terrorists."[23] In addition, the United States, Russia, and China appear to be developing hypersonic weapons that could be mated with air, sea, and land launch platforms. Although HGVs are rather isolated today, the technology could become highly integrated after serial production and deployment in the future.

On the civilian side, hypersonic spacecraft have mostly been used to perform a limited range of tasks related to scientific research, such as launching the Hubble Space Telescope, docking with the Mir space station, or constructing the International Space Station (see Space-Based technology for an assessment of spacecraft and satellites in orbit). At its inception, the US Space Shuttle was designed to perform a wider variety of missions related to the launch, service, and retrieval of both commercial and government satellites. After the *Challenger* accident in 1986, however, most government and especially commercial payloads were shifted to unmanned rocket systems, which became cheaper and safer launch vehicles for satellites. This led in part to the retirement of the Space Shuttle in 2011. Moreover, the marginal cost of development and operation for the Space Shuttle was enormous: NASA's devoted $221 billion to the program overall; the per flight costs varied from $260 million to $806 million (2012 dollars). By contrast, the Falcon 9 rocket is estimated to cost $62 million per launch; the Atlas V costs $109–150 million per launch.[24] The shift away from spacecraft

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[22] James M. Acton, “Silver Bullet? Asking the Right Questions about Conventional Prompt Global Strike,” Carnegie Endowment for International Peace, Brief, September 2013, https://carnegieendowment.org/files/Brief-Acton.pdf. Recent reporting from the Congressional Research Service also found that the Department of Defense "has not established any programs of record, suggesting that it may not have approved requirements for Hypersonic Weapons," see Sayler, “Hypersonic Weapons,” 19.

[23] Acton, “Silver Bullet.”

[24] “Atlas V,” United Launch Services: Atlas V Configurations, accessed January 11, 2022, https://www.ulalaunch.com/rockets/atlas-v; “SpaceX Targets 2021 Commercial Starship Launch,” SpaceNews, June 28, 2019, https://spacenews.com/spacex-targets-2021-commercial-starship-launch/.

as satellite launch platforms also curtailed the spillover potential for hypersonic vehicles, as commercial and even scientific payloads increasingly came to rely on other rocket technology to reach orbit.

Outcomes

No agreements. As of 2021, there have not been any efforts among states at international cooperation or agreements to limit the spread of HGV technology. Several nongovernmental organizations have assessed options for arms control, but none have been considered by national governments.[25] Some analysts point to the indistinguishability between spacecraft and military HGVs as a formidable barrier to cooperation. In 2015, for example, Tong Zhao argued that it would be difficult to ban hypersonic weapons tests while still allowing states to develop spacecraft:

> [Because] this would create such a big loophole that the utility of a test ban would be destroyed. Indeed, the "space planes" whose testing would be allowed … would be very attractive vehicles for delivering munitions or conducting other military missions. Moreover, the development of large civilian space planes might well start with the construction and testing of smaller vehicles—which could be very difficult to distinguish from hypersonic cruise missiles. And it might even be possible to build missiles that in fact were scaled-down versions of large space planes.[26]

Other nongovernmental reports recommend that states voluntarily share information about flight tests or regulate technology transfers through export control regimes, but stop short of identifying ways to surmount the distinguishability problem.[27]

Theory Support: Neutral Support for H3. The outcome neither supports nor undermines our theoretical expectations. We expect states to face significant detection constraints when it comes to distinguishing hypersonic weapons from spacecraft. At least some detection challenges could in principle be surmountable via monitoring and inspections tools. Low integration means that such measures may not raise security risks to unacceptably high levels.

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[25] Heather Williams, "Asymmetric Arms Control and Strategic Stability: Scenarios for Limiting Hypersonic Glide Vehicles," *Journal of Strategic Studies* 42, no. 6 (September 19, 2019): 789–813, https://doi.org/10.1080/01402390.2019.1627521.
[26] Tong Zhao, "Test Ban for Hypersonic Missiles?," *Bulletin of the Atomic Scientists* (blog), June 26, 2015, https://thebulletin.org/roundtable/test-ban-for-hypersonic-missiles/.
[27] John Borrie, Amy Dowler, and Pavel Podvig, "Hypersonic Weapons: A Challenge and Opportunity for Strategic Arms Control," A Study Prepared on the Recommendation of the Secretary-General's Advisory Board on Disarmament Matters (New York: United Nations Office for Disarmament Affairs, February 15, 2019), https://doi.org/10.37559/WMD/19/Hypson1; Speier et al., *Hypersonic Missile Nonproliferation*.

On the other hand, there is also potential for hypersonic weapons to become more distinguishable and integrated in the years ahead. If the United States, Russia, and China follow-through on plans to deploy HGVs, deployment patterns could differentiate weapons from more benign spacecraft; and increase the range and variety of military missions for the technology. If this occurs, we expect arms control agreements to be possible if states can manage the security constraints associated with monitoring highly integrated HGV weapon systems (H4).

Lasers

Technology Definition

A laser refers to technology that emits light through a medium via stimulated emission of electromagnetic radiation. In contrast to other light sources, laser technology is unique because it can produce spatial and temporal coherence in the energy beam. Spatial coherence allows the laser to be focused on small targets and/or across long distances, as exhibited in handheld laser pointers. Temporal coherence means that lasers can emit light along a narrow wavelength spectrum. The specific color of light is tightly coupled with its end use.[1]

As a weapon, lasers come in two primary forms: (1) platforms designed to cause temporary or permanent blindness in human or computer targets, known as 'dazzlers'; (2) high-energy lasers designed to destroy or damage targets, notably missiles and orbital targets. We exclude the latter from this study because the technology has never progressed beyond the experimental stage.[2] Removing this type of laser weapon does not change how we score the dual use attributes. We consider broader applications of laser technology beyond weapons in the dual use attributes.

Time Period Boundaries

We code the debut date for lasers around the first known operational deployment of dazzlers in 1982 onboard Royal Navy vessels during the Falklands war.[3] The basic research concept of a laser emerged earlier in 1957.[4] Despite major advances in laser technology, we find that the dual use attributes remained relatively stable over time, so we treat lasers a single case study.

Lasers, 1982–2020

Distinguishability: <u>High</u>

Military laser weapons are relatively easy to distinguish from the vast array of peaceful laser systems for four reasons.

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[1] Mark Csele, *Fundamentals of Light Sources and Lasers* (Hoboken, NJ: Wiley-Blackwell, 2004); William T. Silfvast, *Laser Fundamentals* (Cambridge, UK: Cambridge University Press, 2004).
[2] For use overviews, see Jason D. Ellis, “Directed-Energy Weapons: Promise and Prospects” (Washington, DC: Center for New American Security, April 2015); Ash Rossiter, “High-Energy Laser Weapons: Overpromising Readiness,” *Parameters* 48, no. 4 (Winter 2018): 33–44.
[3] “UK Deployed Falklands ‘dazzle’ Laser, Documents Show,” *BBC News*, August 1, 2013, sec. UK Politics, https://www.bbc.com/news/uk-politics-23518592.
[4] Nick Taylor, *Laser: The Inventor, the Nobel Laureate, and the Thirty-Year Patent War* (New York, NY: Simon & Schuster, 2000).

First, the physical characteristics of dazzlers are often packaged in different platforms compared to civilian systems with the same laser technology. For example, green diode lasers are used to produce visual effects in many entertainment venues. But these systems have noticeable safety and design features to make them suitable for civilian purposes. By contrast, the green or red laser in a military dazzler is intended to impair human eyesight with a more focused and/or powerful light beam—the functional form of this system is distinct from the entertainment laser.

Second, the development of a laser weapon tends to diverge from its civilian counterpart. Military enterprises can certainly benefit from commercial advances that make lasers better and cheaper to produce. But laser weapons are designed to perform unique functions against targets in a hostile environment. For instance, the infrared laser turrets in counter measure dazzlers must be built to defeat specific sensor packages, whereas civilian communication systems develop different types of fiber mounted infrared lasers to transmit data over long distances. Similarly, human dazzlers need stable (and often mobile) power sources, robust optics, and performance attributes that far exceed the manufacture requirements for most civilian diode lasers.

Third, the deployment pattern for laser weapons can reveal the intended military use. Civilian lasers with the capacity to impair eyesight or damage equipment often include hardware safeguards, such as limits on spatial coherence or power, to avoid accidents. Military dazzlers tend to be mounted or placed for clear point to point contact with the target.[5]

Fourth, although it may be possible to quickly convert some civilian lasers into dazzlers, the efficacy of these devices would be suspect. An off-the-shelf commercial diode laser could certainly be modified to blind an individual, but it may not be useful as a reliable instrument of war. This is especially true for the infrared lasers in counter measure systems that need to be calibrated against targeting sensors.

Integration: <u>High</u> (Military) / <u>High</u> (Civilian)

Laser technology exhibits high integration within the military and within the civilian economy. Although laser weapons perform a limited range of functions in terms of blinding or confusing targets, these systems are deployed across a wide range of military platforms. Dazzlers have enjoyed extensive operational use as part of directional infrared counter measures systems (e.g. laser jammers) on board many large military platforms.[6] Visible light dazzlers have also be deployed as a non-lethal way to stop or warn targets, with various systems mounted on naval vessels, aircraft, battle tanks, and rifles.[7] According to one industry report about the deployment of

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[5] See, for example, Tyler Rogoway, "Check Out This Sailor Holding A Laser Rifle Aboard The Nuclear Submarine USS Minnesota," The Drive, accessed January 10, 2022, https://www.thedrive.com/the-war-zone/35106/check-out-this-sailor-holding-a-laser-dazzler-rifle-aboard-nuclear-submarine-uss-minnesota.
[6] "Large Aircraft Infrared Countermeasures (LAIRCM)," accessed January 10, 2022, https://www.globalsecurity.org/military/systems/aircraft/systems/laircm.htm.
[7] See, for example, the GLARE LA-9/P dazzler. According to its manufacturer, the LA-9/P "remains in service on all US Navy surface vessels," see "GLARE LA-9/P," accessed January 10, 2022, https://bemeyers.com/glare-la-9-p.

nonlethal laser weapons by the US Army in Afghanistan and Iraq, "several types of dazzlers have been used at checkpoints, during urban patrols, on convoys, and for perimeter security."[8] British forces have also used dazzlers in similar missions.[9] Many US naval vessels and submarines have deployed dazzlers to thwart small boat attacks and send a 'shot across the bow' without using live munitions.[10] In 2018, the US Department of Defense accused Chinese personnel of using dazzlers to harm C-130 Hercules pilots flying near Camp Lemonnier in Djibouti.[11] The marginal cost of development and deployment is quite low for these laser weapons. The GLARE LA-9/P dazzler costs around $1–5k per unit, depending on configuration. Military enterprises can also take advantage of advances in laser technology being driven by commercial actors to lower the per unit cost of production and develop more powerful lasers.

On the civilian side, lasers became ubiquitous after the technology matured in the 1970s, with an extensive range of applications in many different sectors, from modern communication and medical capabilities to industrial manufacturing and military targeting systems. The marginal cost of production for civilian lasers varies widely. Cheap diode lasers are mass produced for use in commercial electronics. But bespoke systems for scientific research or specific industrial applications can be much more expensive. Finally, lasers have demonstrated significant spillover potential. Innovations in laser design and production often create new use opportunities in many different sectors.

Outcomes

Agreements with unilateral collection methods. States have reached a number of agreements to limit the employment of laser weapons, largely focusing on how these capabilities are used rather than limiting on banning the possession or production of lasers, with a few exceptions. The first are the Incidents at Sea (INCSEA) agreements[12], which are often signed on a bilateral basis (many INCSEA agreements were signed from 1989–2000 between Russia and western countries). Parties agree not to, "Use lasers in such a manner as to endanger the health of the crew or damage equipment on board a ship or aircraft of the other Party." INCSEA agreements that did not initially include this language on lasers have sometimes been updated to include it, such as was the case for the INCSEA between Russia and Norway, 1990 initially and 2021

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[8] Jeff Hecht, "Laser Dazzlers Are Deployed," Laser Focus World, March 1, 2012, https://www.laserfocusworld.com/lasers-sources/article/16549661/diodepumped-solidstate-lasers-laser-dazzlers-are-deployed.
[9] "British Army Uses Laser Dazzlers to Save Lives," *Wired UK*, September 8, 2010, https://www.wired.co.uk/article/glow-laser.
[10] Rogoway, "Check Out This Sailor Holding A Laser Rifle Aboard The Nuclear Submarine USS Minnesota."
[11] Joseph Trevithick, "US Military Says Chinese Lasers Injured Pilots Flying A C-130 Near Its Base in Djibouti," The Drive, May 3, 2018, https://www.thedrive.com/the-war-zone/20615/us-military-says-chinese-lasers-injured-pilots-flying-a-c-130-near-its-base-in-djibouti.
[12] See, for example, "Agreement Between the Government of The United States of America and the Government of The Union of Soviet Socialist Republics on the Prevention of Incidents On and Over the High Seas" (1972), https://2009-2017.state.gov/t/isn/4791.htm.

updated. INSEA agreements do not have any verification measures. A target state would only detect a violation using its own unilateral capabilities if it were the target of a blinding laser.

Second, agreements on the "Prevention of Dangerous Military Activities" have included limitations on laser weapons. Similar to INSEAs, DMA agreements address behaviors on land and in territorial waters. They include a similar prohibition on the use of lasers, with the parties agreeing to refrain from "using a laser in such a manner that its radiation could cause harm to personnel or damage to equipment of the armed forces of the other Party."[13] DMAs include procedures for notifications and establishing communication for situations when lasers are operational or are being used.[14] This means a somewhat higher degree of information sharing than the INCSEA context, but still not an intrusive method of monitoring or verification.

Finally, in 1995, state parties to the 1980 Convention on Certain Conventional Weapons agreed to the Protocol on Blinding Laser Weapons, which prohibited the use of “laser weapons specifically designed, as their sole combat function or as one of their combat functions, to cause permanent blindness to unenhanced vision.”[15] But as one legal analyst underscored at the time, “no specified verification or enforcement provisions have yet been crafted for Protocol IV … and no compliance procedures whatsoever are set forth in Protocol IV.”[16] A more contemporary analysis by Kelsey Atherton underscored several other large exceptions written into the agreement:

> The first that, while it prohibits weapons “specifically designed, as their sole combat function or as one of their combat functions, to cause permanent blindness to unenhanced vision,” it does not appear to rule out the use of lasers designed for other purposes that may be used circumstantially as a weapon. The greater exception is Article 4, which states “Blinding as an incidental or collateral effect of the legitimate military employment of laser systems, including laser systems used against optical equipment, is not covered by the prohibition of this Protocol.” If the laser is designed to work against camera pods, it’s a legitimate military use, and if the laser targets uninhabited vehicles (like drones), there’s nothing in the protocol against it.[17]

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[13] *Dangerous Activities: Agreement Between the United States of America and the Union of Soviet Socialist Republics, Signed at Moscow June 12, 1989 with Annexes and Agreed Statements* (Washington, DC: Department of State, 1997), 3.

[14] Łukasz Kulesa, Thomas Frear, and Denitsa Raynova, “Managing Hazardous Incidents in the Euro-Atlantic Area: A New Plan of Action,” Policy Brief (European Leadership Network, November 2016), https://www.europeanleadershipnetwork.org/wp-content/uploads/2017/10/ELN-Managing-Hazardous-Incidents-November-2016.pdf.

[15] “Protocol on Blinding Laser Weapons (Protocol IV to the 1980 Geneva Conventions on Certain Conventional Weapons)” (1995), https://ihl-databases.icrc.org/applic/ihl/ihl.nsf/xsp/.ibmmodres/domino/OpenAttachment/applic/ihl/ihl.nsf/70D9427BB965B7CEC12563FB0061CFB2/FULLTEXT/IHL-91-EN.pdf.

[16] Jack H. McCall, Jr., “Blinded by the Light: International Law and the Legality of Anti-Optic Laser Weapons,” *Cornell International Law Journal* 30, no. 1 (1997): 37.

[17] Kelsey Atherton, “Who’s Testing a Laser in Djibouti?,” C4ISRNet, April 27, 2018, https://www.c4isrnet.com/electronic-warfare/2018/04/27/whos-testing-a-laser-in-djibouti/.

States therefore agreed to limit specific types of lasers while allowing most dazzlers to be deployed and used on the battlefield.

Theory Support: Strong for H4. These outcomes all lend strong support for our theory because states used unilateral means to monitor compliance.

Machine Guns

Technology Definition

A machine gun is a weapon designed to automatically fire ammunition continuously with a single pull of its firing mechanism. As long as one holds down the trigger, the weapon will continuously fire until it runs out of ammunition. The machine gun was made possible by all the innovations that made modern rifles supreme alternatives to the smooth-bore musket, as well as increased industrial capacity that made their widespread use possible. Yet, unlike the rifle, the machine gun was not invented, nor was it ever used, for civilian purposes. It is therefore a pure military technology.

Time Period Boundaries

The technology made its debut in 1885 when Hiram Maxim completed the first truly automatic machine gun. We treat the technology as a single case study because both dual use attributes remained stable over time.

Machine Guns, 1885–2020

Distinguishability: <u>High</u>

Machine guns have been highly distinguishable as a pure military technology since their inception in 1885. Hiram Maxim devised a weapon that used the force of its own recoil to eject the spent cartridge and automatically load a new one. Moreover, its rifle-like trigger mechanism meant the weapon would not rely on the laborious hand-cranking required to fire the Gatling gun and mitrailleause. The "Maxim gun" also used a water jacket to keep its barrel cool while firing, thus solving the preceding models' annoying habit of needing to be left idle for a period of time to cool off when their barrels overheated, which often occurred during a battle's climax. Maxim's gun could accurately fire 600 rounds per minute for sustained periods, making it, according to historian Geoffrey Wawro, "The most spectacular European military invention of the late nineteenth century."[1] The Maxim gun resolved problems with earlier machine gun prototypes, which were crude, bulky, and unreliable. For example, the "Gatling gun," saw limited action in the final months of the American Civil War. Shortly thereafter, the French created a similar weapon, the mitrailleause, which they deployed with a similarly limited scope during the Franco-Prussian War. Both weapons were unwieldy contraptions mounted upon a heavy wheeled carriage. They had multiple barrels with a firing and loading mechanism operated by a hand crank. Neither conflict saw extensive use of either weapon—the French army had only 144 mitrailleause in 1870—and

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[1] Quote in Geoffrey Wawro, *Warfare and Society in Europe 1792-1914* (New York: Routledge, 2000), 137. See Also Lee, *Waging War,* 381-2.

neither army had discovered how best to use them, and thus did not train their soldiers to do so. In both cases, the American and French armies used their new weapons as artillery in static, mostly defensive positions.[2] Anatomically, it was a much more complicated weapon requiring advanced machinery for production and maintenance, and it would not have been an effective weapon without barrel rifling, nitrocellulose cartridges, and the loading mechanisms invented for repeating, magazine-fed rifles. Machine guns therefore exhibit clear physical characteristics—such as barrel heat dissipators or belt feeding and open bolt operation—that distinguish them as being purely military weapon systems. In addition, machine guns are neither developed nor deployed for peaceful purposes at all.

Integration: High (Military) / Low (Civilian)

Although machine guns quickly became highly integrated within military enterprises, the technology never offered peaceful applications in the civilian sphere. On the military side, Maxim's invention was both more reliable and sustainable and the weapon itself was easier to place, conceal, and move about the battlefield. It also coincided with the introduction of nitrocellulose to cartridge production, meaning the Maxim gun could engage targets at unprecedented distances with smaller-caliber projectiles, while not having its view obscured by the smoke that black-powder weapons effused with each firing. The machine gun also emerged after advances in manufacturing techniques had enabled mass production of rifles, which enabled militaries to quickly adopt the new technology for widespread use on the battlefield by the early 20th century. Machine guns have since been used in a wide variety of military missions against many different targets, from infantry and aircraft to naval vessels and land vehicles. The weapon plays a key role in area denial and mobile fire support operations. Light and medium machine guns can be employed by infantry, often with the assistance of fixed firing positions such as bipods or tripods. Heavy machine guns are often mounted on motor vehicles, armored vehicles, fixed-wing aircraft, helicopters, and naval vessels.

Outcomes

Agreements with unilateral collection methods. See the outcomes detailed in the Firearms [Rifles] case above, as almost every agreement also includes heavy and light machine guns.

Theory Support: Strong for H4. These outcomes all lend strong support for our theory because states used unilateral means to monitor compliance.

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[2] Wayne E. Lee, *Waging War: Conflict, Culture, and Innovation in World History* (New York: Oxford University Press, 2016), 378; William H. McNeill, *The Pursuit of Power: Technology, Armed Force, and Society since A.D. 1000* (Chicago: The University of Chicago Press, 1984), 251; Wawro, *The Franco-Prussian War,* 53-4, 91, 99-100, 124, 129, 183.

Maritime Vessels

Technology Definition

Metal-clad maritime vessels refer to any seaworthy, ocean-going ship which is constructed from iron, steel, or other metals.[1] Use of iron in shipbuilding began in the civilian maritime industry because it proved cheaper, more abundant, and more suitable than wood for use in conjunction with the steam engine.[2] This technique spread to the military realm because metal provided greater armor and protection at a time when naval ordnance was wreaking havoc on wooden hulls.[3] In 1869, an established pattern for military vessels emerged with the British *HMS Devastation*, which utilized a mast-less design that placed its main, turreted armament on an elevated breastwork atop the hull.[4] The construction of the *HMS Dreadnought* in 1905, a new capital ship armed with large-caliber guns paired in five turrets and powered by lighter-weight turbine engines, drove great powers to develop military vessels with greater firepower, speed, and armor.[5] The dreadnoughts remained the dominant capital ships until they were supplanted by aircraft carriers during World War II. Since then, aircraft carriers have

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[1] This extends to vessels constructed through riveting, welding, or more advanced mass-production techniques. This does not include ships only constructed with features such as iron bracings. As a ship-building material, metal has been ubiquitous since the late-19th and 20th centuries. For overviews at the time, see John Grantham, *Iron Ship-Building: with Practical Illustrations, 5th edition* (London: Virtue and Co., 1868); William Fairbairn, *Treatise on Iron Ship Building: Its History and Progress* (London: Longmans, Green, and Co., 1865); Edward James Reed, *Shipbuilding in Iron and Steel: A Practical Treatise* (London: John Murray, Albemarle Street, 1869). See also Peter Goodwin, "The Influence of Iron in Ship Construction: 1660 to 1830," *Maritime Park Association*, 1997, https://maritime.org/conf/conf-goodwin.htm; Hanlon, "Evolving Comparative Advantage in International Shipbuilding"; Harley, "British Shipbuilding and Merchant Shipping: 1850-1890"; Graeme J. Milne, "North East England, 1850-1914: The Dynamics of a Maritime Industrial Region" (Woodbridge: The Boydell Press, 2006); "Ships and Boats: 1840-1950: Introduction to Heritage Assets" *Historic England*, 2012, https://historicengland.org.uk/images-books/publications/iha-ships-boats-1840-1950/heag133-ships-and-boats-1840-1950-iha/.

[2] W. Walker Hanlon, "Evolving Comparative Advantage in International Shipbuilding During the Transition from Wood to Steel," *NYU Stern School of Business & NBER*, July 20, 2017, https://eh.net/eha/wp-content/uploads/2017/08/Hanlon.pdf; Charles K. Harley, "British Shipbuilding and Merchant Shipping: 1850-1890," *The Journal of Economic History*, 30, no. 1 (March 1970): 262-266, https://www.jstor.org/stable/2116741.

[3] Karl Lautenschlager, "Technology and the Evolution of Naval Warfare," *International Security*, vol. 8, no. 2 (Fall 1983), https://www.jstor.org/stable/2538594; James Phinney Baxter, *The Introduction of the Ironclad Warship*, (Cambridge: Harvard University Press, 1933): 17-32, 33-34; Robert Gardiner and Andrew D. Lambert, *Steam, Steel & Shellfire: The Steam Warship 1815-1905* (Annapolis: Naval Institute Press, 1992), for other early civilian iron vessels, see Ewan Corlett, *The Iron Ship: The Story of Brunel's SS Great Britain* (Bradford-on-Avon: Moonraker Press, 1975).

[4] J. W. King, *European Ships of War and Their Armament, Naval Administration and Economy, Marine Constructions and Appliances, Dock-Yards, etc., etc.* (Washington: Government Printing Office, 1877): 35-46; Stanley Sandler, "The Emergence of the Modern Capital Ship," *Technology and Culture*, vol. 11, no. 4 (October 1970): 576-595, https://www.jstor.org/stable/3102692.

[5] Charles H. Fairbanks Jr., "The Origins of the Dreadnought Revolution: A Historiographical Essay," *The International History Review*, vol. 13, no. 2 (May 1991): 246-272, https://www.jstor.org/stable/40106366; Lawrence Sondhaus, *Naval Warfare, 1815-1914* (London and New York: Routledge, 2000): 197-202; Lautenschlager, "Technology and the Evolution of Naval Warfare," 18-20.

remained the centerpieces of modern navies.[6] One note on terminology: we use the term “naval” to refer to the military version of general “maritime” vessels.

Time Period Boundaries

We code the debut of metal-clad naval vessels in 1869 with the introduction of the *HMS Devastation*. Despite significant innovations in production and design, the technology exhibited little variation in distinguishability or integration over the next 150 years. We therefore treat maritime vessels as a single temporal case study.

Maritime Vessels, 1869–2020

Distinguishability: <u>High</u>

Metal-clad maritime vessels have always been highly distinguishable for three reasons. First, military and civilian ships possess distinct physical characteristics. The most observable features on military vessels are armament, from large-caliber guns and missiles to protective measures such as heavy armor, and advanced propulsion systems.[7] Military ships must be designed to host weapon systems and special sensor packages. Armor, such as torpedo belts and bulges, is used, particularly in capital ships, to protect against submarines and carry additional weapons.[8] By contrast, civilian vessels are much slower and simpler in design with relatively basic propulsion and navigation systems. For example, sonar and radar systems are far less complex on civilian ships because they need not map great distances with high resolution or identify

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[6] Norman Polmar and Minoru Genda, *Aircraft Carriers: A History of Carrier Aviation and Its Influence on World Events, Volume 1: 1909-1945* (Washington, D.C.: University of Nebraska Press, 2006): 1-21; 23-38; 114-118, 165-175; Norman Polmar, *Aircraft Carriers: A History of Carrier Aviation and Its Influence on World Events, Volume 2: 1946-2006* (Dulles: Potomac Books, Inc., 2008). See also Erik Gartzke and Jon R. Lindsay, “The Influence of Sea Power on Politics: Domain- and Platform-Specific Attributes of Material Capabilities,” *Security Studies* 29, no. 4 (August 7, 2020): 601–36, https://doi.org/10.1080/09636412.2020.1811450.

[7] With only a few exceptions, nuclear propulsion is used almost entirely in military applications for vessels.

[8] For examples of the specific alloys and metals used for military armor since the dawn of the ironclads, see Nathan Okun, “Table of Metallurgical Properties of Naval Armor and Construction Materials,” *NavWeaps*, (last updated September 26, 2009), http://www.navweaps.com/index_nathan/metalprpsept2009.php. See also the distinguishing factor of protection in warship design; “Ship Shapes: Anatomy and Types of Vessels,” *Naval History and Heritage Command*, December 9, 1942, https://www.history.navy.mil/content/dam/nhhc/research/library/online-reading-room/ships/ShipShapes/Ship%20Shape%20Pamphlet%20-%20PDF.pdf, as well as Lieutenant Edward W. Very, *The Development of Armor for Naval Use* (Annapolis: U.S. Naval Institute, 1883). Bulges can also be used in civilian ships, albeit for different purposes, such as increasing stability or the overall load, see Philip Sims, “Bulging Merchant Ships,” *Naval Engineers Journal*, vol. 119, no. 3 (November 1, 2007) 53-65, https://www.ingentaconnect.com/content/asne/nej/2007/00000119/00000003/art00018; Philip Sims, “Bulging Warships,” *Naval Engineers Journal,* vol. 101, no. 6, (November 1, 1989): 24-41, https://www.ingentaconnect.com/content/asne/nej/1989/00000101/00000006/art00008.

and engage threats. Modern commercial ships also tend to be bigger than their military counterparts, and they resemble massive metal boxes.

Second, the construction of military vessels follows a bespoke process, whereas commercial ships are built in a mass-production industry that is reliant on the simple steel forming and welding processes. Military shipbuilding involves the installation of high-value, sensitive equipment and the use of much rarer, cutting-edge, and lightweight materials for increased speed.[9]

Third, military and civilian ships adhere to different deployment patterns around the world. Aside from a few notable exceptions, civilian ships have not been widely used in military operations.[10] Civilian and military vessels fly under distinct ensigns for many countries and are often listed under separate naval registries, making them clearly distinct from one another at sea.[11]

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[9] John Birkler, Denis Rushworth, James Chiesa, Hans Pung, Mark V. Arena, John F. Schank, "Differences Between Military and Commercial Shipbuilding: Implications for the United Kingdom's Ministry of Defence," *RAND Europe*, 2005, https://www.rand.org/content/dam/rand/pubs/monographs/2005/RAND_MG236.pdf, xv; P. Noury, B. Hayman, D. McGeorge, and J. Weitzenbock, "Lightweight Construction for Advanced Shipbuilding – Recent Development," *Det Norske Veritas*, January 2002, http://www.foradenizcilik.com/kutuphane/lightweight.pdf.

[10] The use of Q-Ships during World War I and World War II represent one of the few cases of military ships being disguised as civilian craft in order to lure enemy submarines into a surface attack. The use of this kind of anti-submarine warfare contributed to the onset of unrestricted submarine warfare and the collapse of the so-called cruiser rules. See E. Keble Chatterton, *Q-Ships and Their Story* (London: Sidgwick and Jackson, 1922); Carson I. A. Ritchie, *Q-Ships* (Lavenham and Suffolk: Terence Dalton Limited, 1985); Kenneth M. Beyer, *Q-Ships versus U-Boats: America's Secret Project* (Annapolis: Naval Institute Press, 1999); Michael N. Schmitt and Leslie C. Green, "Submarine Warfare: With Emphasis on the 1936 London Protocol," within *Levie on the Law of War* (Newport: Naval War College, 1998): 297-306. The use of merchant aircraft carriers (MACs) during World War II represented another maritime grey area given that these ships were modified tankers and grain transport ships. They flew under civilian ensigns yet operated aircraft as a defensive, anti-submarine weapons platform. See Schmitt and Green, "Submarine Warfare: With Emphasis on the 1936 London Protocol," 314-321; John R. Mably, *The Effectiveness of Merchant Aircraft Carriers* (Master's Thesis, The University of Brighton, 2004); Captain R. C. Bayne R. N., "Merchant Ship Aircraft Carriers," *Royal United Services Institution Journal*, vol. 92, no. 568 (1947): 548-553.

[11] However, the People's Republic of China has recently deployed civilian and commercial ships for ostensibly military purposes, signaling a potential shift away from traditional patterns of usage that have restricted civilian and military ships to their respective spheres. See Samir Puri and Greg Austin, "What the Whitsun Reef incident tells us about China's future operations at sea," *IISS*, April 9, 2021, https://www.iiss.org/blogs/analysis/2021/04/whitsun-reef-incident-china; Derek Grossman and Logan Ma, "A Short History of China's Fishing Militia and What It May Tell Us," *The RAND Blog*, April 6, 2020, https://www.rand.org/blog/2020/04/a-short-history-of-chinas-fishing-militia-and-what.html; Shuxian Luo and Jonathan G. Panter, "China's Maritime Militia and Fishing Fleets," *Military Review*, January-February 2021, https://www.armyupress.army.mil/Journals/Military-Review/English-Edition-Archives/January-February-2021/Panter-Maritime-Militia/; Peter Wood, "Dual-Use Ships and Facilities Send Mixed Message in South China Sea," *The Jamestown Foundation*, July 2, 2015, https://jamestown.org/program/dual-use-ships-and-facilities-send-mixed-message-in-south-china-sea/. See also Jonathan D. Caverley and Peter Dombrowski, "Cruising for a Bruising: Maritime Competition in an Anti-Access Age," *Security Studies* 29, no. 4 (August 7, 2020): 671–700, https://doi.org/10.1080/09636412.2020.1811460.

Integration: <u>High</u> (Military) / <u>High</u> (Civilian)

Metal-clad vessels quickly became highly integrated within both civilian and military realms after the technology matured in the late-19th century. Within the civilian context, metal-clad vessels have long been used for convoys, transporting goods and raw materials, whaling and fishing, cruises and transoceanic travel, as well as ocean research, among other things. Within the military context, metal-clad vessels have been used for ship-to-ship combat, amphibious landings, coastal bombardments, long-distance air strikes and force projection from aircraft carriers, anti-submarine warfare, blockades, protection of supply lines, as well as coastal defense and patrol, among other things.

Metal-clad vessels fulfill the same general purpose as their wooden predecessors in naval combat, although the specific classes of ships and their functions have evolved over time with technological innovation. Entire navies have continued to modernize and are heavily integrated with new innovations—a fact that has been true throughout history with significant technologies such as the diesel engine, radar, sonar, nuclear-power propulsion systems, and cruise missile technology, to only name a few. In this way, modern warships, especially since the 20th century, have functioned as advanced maritime weapons platforms. However, the use of more advanced systems mean that military ships cost far more than their civilian counterparts in many cases.[12]

Outcomes

<u>Agreements with unilateral collection methods.</u> States reached several agreements (1899; 1907; 1909) that established rules for naval warfare and the conversion of

[12] A single aircraft carrier from the Ford Class of the United States CVN-78 aircraft carrier program costs far more ($13.3 billion for the first ship) than any commercial vessel cited in a 2013 United States Government Accountability Office report, the most expensive of which was $1.4 billion. See "Navy Shipbuilding: Opportunities Exist to Improve Practices Affecting Quality," *United States Government Accountability Office*, November 2013, https://www.gao.gov/assets/gao-14-122.pdf: 89, and "Navy Ford (CVN-78) Class Aircraft Carrier Program: Background and Issues for Congress," Congressional Research Service Report, July 29, 2021, https://sgp.fas.org/crs/weapons/RS20643.pdf; Office of the Chief of Naval Operations, "Report to Congress on the Annual Long-Range Plan for Construction of Naval Vessels," *Office of Secretary of Defense*, December 9, 2020, https://media.defense.gov/2020/Dec/10/2002549918/-1/-1/1/SHIPBUILDING%20PLAN%20DEC%2020_NAVY_OSD_OMB_FINAL.PDF.

merchant ships in war-ships.[13] The Washington (1922)[14] and London (1930; 1936)[15] Naval Treaties established stringent tonnage limits for each great naval power on capital ships (battleships) and aircraft carriers, as well as design and size limits on destroyers, submarines, and auxiliary ships. These agreements lacked cooperative monitoring mechanisms. States relied on their own national means to monitor and verify compliance. Military ships were large (hard to hide) and often built in plain sight over long periods of time. This made it easy for intelligence agencies to determine the civil or military nature of construction at shipyards, and then verify whether missile vessels met the treaty limitations.[16] More recently, the United Nations Register of Conventional Arms (1991) reporting mechanism for UN member states to detail the transfer or production of conventional arms. The register applies to vessels armed and equipped for military use with a standard displacement of 500 metric tons or above, and those with a standard displacement of less than 500 metric tons, equipped for launching missiles with a range of at least 25 kilometers or torpedoes with similar range. The register is voluntary and has no formal monitoring mechanism.[17] Similarly, the Wassenaar Agreement (1995)

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[13] "Laws of War: Adaptation to Maritime Warfare of Principles of Geneva Convention of 1864 (Hague, III); July 29,1899," *Yale Law School: Lillian Goldman Law Library, The Avalon Project*, 2008, https://avalon.law.yale.edu/19th_century/hague993.asp; "Laws of War: Conversion of Merchant Ships into War Ships (Hague VII); October 18, 1907," *Yale Law School: Lillian Goldman Law Library, The Avalon Project*, 2008, https://avalon.law.yale.edu/20th_century/hague07.asp; "Declaration Concerning the Laws of Naval War, London," *International Committee of the Red Cross*, February 26, 1909, https://ihl-databases.icrc.org/applic/ihl/ihl.nsf/Treaty.xsp?action=openDocument&documentId=E08DDA302F7397ADC12563CD002D68C5.

[14] The treaty prevented an unrestricted build-up of capital ships in the short-term, but it triggered an arms race of "treaty cruisers," heavy cruisers built up to the limits of the treaty. Allan Nevins, "The Naval Conference Fails," *Current History (1916-1940)*, vol. 43, no. 6 (March 1936): 614-619, https://www.jstor.org/stable/45337657; Richard Dean Burns, "Inspection of the Mandates, 1919-1941," *Pacific Historical Review*, vol. 37, no. 4 (November 1968): 445-462, https://www.jstor.org/stable/3637189; "The Washington Naval Conference," *Office of the Historian (U.S. Department of State)*, https://history.state.gov/milestones/1921-1936/naval-conference; "Conference on the Limitation of Armament," November 12, 1921-February 6, 1922, from *Papers Relating to the Foreign Relations of the United States: 1922, Vol. 1*: 247-266, https://www.ibiblio.org/pha/pre-war/1922/nav_lim.html.

[15] "Abstract of Testimony on Certain Salient Questions of the London Naval Treaty Given Before the Committee on Naval Affairs of the Senate," *U.S. Senate, 71st Congress, 2nd Session, Document no. 197,* May 14-29, 1930, https://li.proquest.com/elhpdf/histcontext/9220-S.doc.197.pdf; "The 1930 London Naval Treaty," *ww2ships*, http://ww2ships.com/documents/doc0005-london1930.shtml; "The London Naval Conference, 1930," *Office of the Historian (U.S. Department of State)*, https://history.state.gov/milestones/1921-1936/naval-conference; "London Conference of 1936," *NavWeaps*, March 25, 1936 (updated December 29, 2017), http://www.navweaps.com/index_tech/tech-089_London_Treaty_1936.php; Meredith William Berg, "Admiral William H. Standley and The Second London Naval Treaty," *The Historian*, vol. 33, no. 2 (February 1971): 215-236, https://www.jstor.org/stable/24442670. The Anglo-German Naval Agreement (1935) also sought to limit the size of the *Kriegsmarine* to 35 percent of the total tonnage of the Royal Navy, see "Anglo/German Agreement of 1935," *NavWeaps*, June 18, 1935 (updated December 29, 2017) http://www.navweaps.com/index_tech/tech-089_Anglo_German_Agreement_1935.php.

[16] For a more detailed overview of intelligence collection requirements for these treaties, see Andrew J. Coe and Jane Vaynman, "Why Arms Control Is So Rare," *American Political Science Review* 114, no. 2 (May 2020): 350, https://doi.org/10.1017/S000305541900073X.

[17] "Categories of major conventional arms," *UNROCA*, (undated), https://www.unroca.org/categories; Siemon T. Wezeman, "Reporting to the United Nations Register of Conventional Arms for 2017," *SIPRI*,

seeks to promote transparency into the sale, trade, and distribution of naval vessels armed and equipped for military use with a standard displacement of 750 metric tons or above, and those with a standard displacement of less than 750 metric tons equipped for launching missiles with a range of at least 25 km or torpedoes with a similar range. The treaty is voluntary and has no formal mechanisms for enforcement or verification.[18]

Theory Support: Strong for H4. These outcomes all lend strong support for our theory because states used unilateral means to monitor compliance.

June 2019, https://www.sipri.org/sites/default/files/2019-06/bp_1906_unroca.pdf; Siemon T. Wezeman, "The Future of the United Nations Register of Conventional Arms," *SIPRI Policy Paper No. 4,* August 2003, https://www.sipri.org/sites/default/files/files/PP/SIPRIPP04.pdf.

[18] "The Wassenaar Arrangement on Export Controls for Conventional Arms and Dual-Use Goods and Technologies," *Wassenaar Arrangement Secretariat,* January 2006, https://inecip.org/wp-content/uploads/Acuerdo-Wassenaar.pdf; "Wassenaar Arrangement," *Nuclear Threat Initiative*, (updated July 14, 2020), https://www.nti.org/learn/treaties-and-regimes/wassenaar-arrangement/.

Motor Vehicles

Technology Definition

A "motor vehicle" is a self-propelled vehicle for carrying people or light cargo. The typical motor vehicle has four wheels powered by an engine mounted on a chassis that can ride on standard roads. This feature differentiates automobiles from larger trucks. The technology originated in 1885 with the German Benz Patent-Motorwagen, and became widely available after 1908 as the Ford Motor Company pioneered mass production of the Model T.[1] Although motor vehicles are designed to serve civilian purposes, the technology can be readily converted into military use as a "non-standard tactical vehicle" or a "technical" in the parlance of asymmetric warfare.[2] In the First World War, Great Britain mounted light and medium machine guns to the Ford Model T for use in desert attacks.[3] The development of four-wheel drive pickup trucks in the late-1960s enabled the emergence of the modern "technical" because a variety of weapons could be quickly mounted to rear cargo bed, from heavy machine guns to artillery and rocket launchers.

Time Period Boundaries

We code the debut of motor vehicle technology in 1885 with the introduction of the German Benz Patent-Motorwagen. The dual use attributes remained stable over time, so we treat the technology as a single case study.

Motor Vehicle, 1885–2020

Distinguishability: <u>Low</u>

Many civilian pickup trucks and sport utility vehicles have been converted for military use, the most common being the Toyota HiLux and Land Cruiser. The "technical" is indistinguishable from its civilian counterpart for three reasons. First, civilian and military pickup trucks share the same vehicle base. The sole distinguishing feature is the presence of a rear-mounted heavy weapon, which can be obscured or removed from view. "With the weapons stripped out," Neville notes, "the technical is just a simple truck used to transport goods to market."[4] Second, commercial pickup trucks can be readily

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[1] Michael L. Berger, *The Automobile in American History and Culture: A Reference Guide* (Westport, CN: Greenwood, 2001).
[2] Leigh Neville, *Technicals: Non-Standard Tactical Vehicles from the Great Toyota War to Modern Special Forces* (Oxford, UK: Bloomsbury Publishing, 2018); Ravi Somaiya, “Why Rebel Groups Love the Toyota Hilux,” Newsweek, October 14, 2010, https://www.newsweek.com/why-rebel-groups-love-toyota-hilux-74195.
[3] Neville, *Technicals*, 6.
[4] Neville, 6.

sourced and transformed into technicals, especially in the developing world where the Toyota HiLux is the automotive workhorse for many civilians.[5] With few modifications, the vehicle can be outfitted to perform light attack missions. Third, technicals can be deployed to blend in with civilian traffic. Toyota pickup trucks are ubiquitous in many developing countries. This creates a "cloak of deniability" under which the technical can operate without being positively identified until it deploys a clear weapon system.

Integration: High (Military) / High (Civilian)

Motor vehicles have long exhibited a high degree of integration within both military enterprises and the civilian economy for three reasons. First, the automobile performs a wide range of tasks across many different sectors of the civilian economy. Lightweight four-wheel drive trucks with high ground clearance and large tires are ideal for off-road work in rugged terrain, but can also run on standard paved roads. This also makes them useful for many different military situations where speed, maneuverability, and deniability are paramount. By contrast, armored vehicles are far less nimble as they are designed to perform a limited range of missions.[6] Second, the marginal cost of developing motor vehicles and even non-standard tactical vehicles is quite low. The automobile industry pioneered several major breakthroughs in manufacturing (mass production and later lean production) that dramatically lowered the price of cars and trucks for consumers throughout the 20th century.[7] Technicals are also relatively cheap to develop, maintain, and operate.[8] They can be fixed with readily available spare parts and require no specialized logistical support. For example, Battelle converts the Toyota HiLux or Land Cruiser into a high-end technical for roughly $300,000 a unit. By contrast, the M2 Bradley Fighting Vehicle costs around $5,000,000 per unit, and requires training and continuous maintenance to operate.[9] Third, the automobile industry has been responsible for driving innovations in numerous other industries, from component manufacturing and material science to energy storage more recently. The "high linkage intensity" of the industry means that motor vehicle development generates significant spillover effects.

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[5] Kyle Mizokami, "The Toyota Pickup Truck Is the War Chariot of the Third World," *War Is Boring* (blog), March 14, 2017, https://medium.com/war-is-boring/the-toyota-pickup-truck-is-the-war-chariot-of-the-third-world-ea4a121e948b.
[6] Hogg, *Armour in Conflict*.
[7] Peter Dicken, "'Wheels of Change': The Automobile Industry," in *Global Shift: Mapping the Changing Contours of the World Economy* (SAGE, 2014).
[8] Neville, *Technicals*, 5.
[9] Kyle Mizokami, "How U.S. Special Forces Get Their Armored Pickups," Popular Mechanics, April 5, 2018, https://www.popularmechanics.com/military/a19694154/how-us-special-forces-get-their-armored-pickups/; "Armored & Unarmored Commercial Vehicles," Battelle, accessed October 17, 2021, https://www.battelle.org/government-offerings/national-security/payloads-platforms-controls/armored-unarmored-commercial-vehicles.

Outcomes

No agreements. Although armored vehicles have often been included in armistice and even arms control treaties, motor vehicles in general that begin life as a commercial design have never been subject to such limitations.

Theory Support: Strong for H2.

Nuclear

Technology Definition

We define the military uses of nuclear technology around the weapon or so-called "physics package" where atoms undergo fission and/or fusion to release energy. Nuclear weapons can be mated with various platforms, notably rockets and cruise missiles, which we consider as separate technology categories.

Our definition focuses on the two main types of first-generation fission weapons: (1) a simple “gun-type” physics package slams together masses of highly enriched uranium (HEU) to ignite a supercritical nuclear chain reaction; (2) a basic “implosion-type” weapon uses high explosives to compress a subcritical sphere of plutonium into a denser, supercritical mass that triggers the explosive reaction. More advanced two-stage thermonuclear weapons also use a fission primary to ignite fusion material. Nuclear weapons therefore require a core of fissile material—enriched uranium or plutonium—to ignite the fission and/or fusion explosive reaction. Without this critical ingredient, no "physics" can occur in the weapon package.[1]

The civilian uses of nuclear technology center around the controlled process of splitting atomic nuclei to release energy. Fission serves as the basis to produce large amounts of electricity in nuclear reactors (radioisotopes also play a role in medical diagnostics and treatment). The problem is that nuclear energy enterprises also produce and use fissile material for peaceful purposes.[2] Our definition of nuclear technology therefore includes the capacity to produce fissile material along the "front" and "back" ends of the nuclear fuel cycle as a key dual use element. Given the central role of these capabilities, we provide a brief primer on the two main fissile material production pathways.

The enrichment pathway along the “front end” of the nuclear fuel cycle starts by mining natural uranium from the ground with an isotopic composition of U-238 (99.3%) and U-235 (0.7%). Some older reactors can use natural uranium as fuel, but U-238 cannot sustain the rate of fission needed to fuel modern light water reactors or atomic weapons. But U-235 fissions at the higher rate required for fast chain reactions. Enrichment refers to the process of separating out the minute amount of U-235 from natural uranium. A range of enrichment options exist, from gaseous diffusion to the

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[1] For overviews of nuclear weapons technology, see “Fission Weapons,” in *Restricted Data Declassification Decisions, 1946 to the Present* (Washington, DC: US Department of Energy, Office of Declassification, RDD- 7, 2002); Bruce T. Goodwin, “Nuclear Weapons Technology 101 For Policy Wonks,” Center for Global Security Research (Lawrence Livermore National Laboratory, August 2021); Robert Harney et al., “Anatomy of a Project to Produce a First Nuclear Weapon,” *Science & Global Security* 14, no. 2–3 (December 2006): 163–82; Peter D. Zimmerman, “Proliferation: Bronze Medal Technology Is Enough,” *Orbis* 38, no. 1 (December 1, 1994): 67–82, https://doi.org/10.1016/0030-4387(94)90106-6.

[2] See Matthew Fuhrmann and Benjamin Tkach, “Almost Nuclear: Introducing the Nuclear Latency Dataset,” *Conflict Management and Peace Science* 32, no. 4 (September 1, 2015): 443–61, https://doi.org/10.1177/0738894214559672; Andreas Persbo, “Latent Nuclear Power, Hedging, and Irreversibility,” in *Nuclear Latency and Hedging: Concepts, History, and Issues*, ed. Joseph F. Pilat, Nuclear Proliferation International History Program (Washington, DC: Woodrow Wilson Center Press, 2019), 43–72.

more modern centrifuge techniques.[3] Enrichment is integral to fueling most modern nuclear power plants in operation today, which require fuel rods with uranium to be enriched to 3%–5% U-235. The dual use issue emerges here because the same plant can be used to keep enriching uranium until it contains enough fissile U-235 for a weapon.

At the "back end" of the nuclear fuel cycle, the reprocessing method extracts another fissile material—plutonium—from irradiated uranium (e.g., spent fuel from a nuclear reactor). Plutonium is formed when uranium-238 sustains fission, most often in reactors fueled with uranium. The irradiated rods undergo processing to separate the plutonium from the other elements.[4] Nuclear energy programs can reprocess fuel to manage the toxic nuclear reactor waste. Plutonium can also be fed back into the fuel cycle to power special fast and breeder reactors. However, the fissile nature of plutonium- 239 makes it an ideal material for crafting the heart of an atomic weapon.

Time Period Boundaries

We code the debut of the nuclear fuel cycle in 1945 with the genesis of the main military application: atomic weapons. Civilian nuclear energy programs emerged later in 1954.

Nuclear, 1945–2020

Distinguishability: <u>Low</u>

The peaceful uses of nuclear fuel cycle technology are difficult to distinguish from military applications for four reasons. First, civil and military programs draw from the same pool of enrichment and reprocessing options. As Matthew Fuhrmann finds, “much of the technology needed for a civilian nuclear program is indistinguishable from what states require to build nuclear weapons.”[5] At the dawn of the atomic energy era in 1955, for instance, Gerard C. Smith, the Special Assistant to Secretary Dulles for Atomic Energy, lamented that many countries would soon produce “large quantities of fissionable material equally useful for peaceful or military purposes. This is not a pleasant prospect.”[6] There is no technical basis to draw a boundary between civil and military applications. A large stockpile of plutonium, for instance, is agnostic on whether it is used to fuel fast reactors or build weapons.

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[3] Houston G. Wood, Alexander Glaser, and R. Scott Kemp, “The Gas Centrifuge and Nuclear Weapons Proliferation,” *Physics Today* 61, no. 9 (September 2008): 40–45, https://doi.org/10.1063/1.2982121.
[4] E.R. Irish and W.H. Reas, “The PUREX Process: A Solvent Extraction Reprocessing Method for Irradiated Uranium” (Richland, WA: Hanford Atomic Products Operation, April 1, 1957), https://doi.org/10.2172/4341712.
[5] Matthew Fuhrmann, “Splitting Atoms: Why Do Countries Build Nuclear Power Plants?,” *International Interactions* 38, no. 1 (January 1, 2012): 31, https://doi.org/10.1080/03050629.2012.640209.
[6] Gerard C. Smith, “Observations on the Problem of Controlling Against Diversion of Fissionable Material from Nuclear Power,” Policy Paper, Department of State, 17 September 1955, *DNSA*, #NN00050.

Second, the development pathway for pursuing the bomb need not diverge from a peaceful endeavor until it comes time to weaponize fissile material. "Once a nation has a civilian atomic energy program encompassing fairly large reactors and processing facilities," the Central Intelligence Agency underscored in 1957, "it requires only relatively little investment in an ordnance laboratory and research in weapons design to initiate a weapons program."[7] Countries can take the hardest step toward the bomb by mastering the nuclear fuel cycle in plain sight for ostensibly peaceful purposes. Such programs set the technical foundation to build the bomb on short notice at a later date.

Third, the deployment pattern for civil nuclear fuel cycle facilities looks like the fissile material production stage in a weapons program. Unless infrastructure needs to be hidden or hardened at dedicated military sites, nuclear weapons programs can emulate atomic energy enterprises. States can openly accumulate enriched uranium or plutonium as part of an aboveboard energy program. But this material and knowledge would present a perennial "threat to security," an American official presciently argued in 1955, because it could always be used to build the bomb.[8] In the ensuing years, this issue increasingly vexed American intelligence estimates of foreign nuclear programs. "The plutonium route to a weapons program has become a well-marked trail," a 1963 US National Intelligence Estimate on proliferation highlighted, "and one which in its earlier stages is scarcely *distinguishable* from a purely peaceful program."[9] Similarly, in 1975, a CIA study found that "the civilian/military distinction in nuclear resources is fading ... as nuclear power installations continue to evolve towards similarity with the technology needed to make nuclear explosives."[10]

Fourth, the conversion speed for nuclear technology is rapid once one accumulates enough fissile material to build the core an atomic weapon. This means that "the nations with the most developed peaceful programs will be nearest to a military bomb capability," the State Department concluded in 1968.[11]

The indistinguishable nature of nuclear technology drove up the transparency requirements for verifying peaceful uses. During the initial halcyon era for atomic energy, US officials determined that on-site inspections of civil nuclear programs would be needed to check compliance with nonproliferation obligations. "Efficient monitoring may require complete access to plants and full operational knowledge," Gerald Smith noted as the Eisenhower administration formulated its atomic assistance program in 1955.[12] British officials reached similar conclusions at the time, telling the Americans

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[7] National Intelligence Estimate, "Nuclear Weapons Production in Fourth Countries: Likelihood and Consequences," Director of Central Intelligence, 18 June 1957, *NSA EBB 155*, https://nsarchive2.gwu.edu/NSAEBB/NSAEBB155/prolif-2.pdf.
[8] Philip J. Farley, "Control of Peaceful Uses of Atomic Energy," Memorandum for File, Department of States, 7 October 1955, *DNSA* #NN00052.
[9] National Intelligence Estimate, "Likelihood and Consequences of a Proliferation of Nuclear Weapons Systems," Director of Central Intelligence, 28 June 1963, *NSA EBB 155*, https://nsarchive2.gwu.edu/NSAEBB/NSAEBB155/prolif-8.pdf, emphasis added.
[10] Central Intelligence Agency, "Managing Nuclear Proliferation: The Politics of Limited Choice," Research Study, December 1975, https://www.cia.gov/readingroom/docs/CIA-RDP86T00608R000600170035-1.pdf
[11] Henry Owen to Secretary Dean Rusk, "After NPT, What," Memo, 10 June 1968, enclosing Policy Planning Council study of the same title, 28 May 1968, Department of State, *NSA EBB 253*, https://nsarchive2.gwu.edu//nukevault/ebb253/doc27.pdf.
[12] Smith, "Observations on the Problem."

that the “diversion [of] nuclear fuel from such [civil] power stations [for] military purposes could be prevented only by effective system [of] inspection and accounting.”[13] The International Atomic Energy Agency (IAEA) was created in 1957 to help solve this information problem by inspecting nuclear programs declared for peaceful purposes. In 1965, Glenn Seaborg, the Chairman of the Atomic Energy Commission, provided the White House with an assessment of the monitoring measures the IAEA would need to adopt as gas centrifuge enrichment technology reached commercial maturity. “Such inspection would involve continuous ground access at the perimeter of the process buildings, measurement of electrical input to the plant, and measurement of permitter uranium input and declared product output and uranium tails.”[14] As Seaborg’s study illustrated, it is possible to verify the peaceful uses of nuclear fuel cycle facilities and even fissile material. But comprehensive physical safeguards and intensive inspections are necessary to detect military violations.

Integration: Low (Military) / Low (Civilian)

Nuclear technology scores low across all attributes of integration. Although nuclear reactor and fuel cycle assets can have major economic and strategic effects, the technology itself is sequestered from other civil and military capabilities in three ways.

First, the range and variety of uses for the nuclear fuel cycle is limited to the production of electricity, explosives, or radioisotopes. This narrow menu of applications has not expanded over the last seven decades. Nuclear reactors and fissile material production facilities remain isolated to niche commercial sectors or specialized military enterprises. Second, the marginal cost of developing atomic weapons or energy enterprises is quite high.[15] Large nuclear projects require significant resources, even though innovations sometimes lower barriers to entry. For example, the jump from gaseous diffusion plants to gas centrifuges in the 1970s made it cheaper and easier to enrich uranium.[16] Yet building centrifuge enrichment plants remained a resource intensive endeavor. Even commercial nuclear power plants can be prohibitively costly to bring online, as evidenced by Westinghouse declaring bankruptcy in 2017 after several reactor build projects ran over budget.[17] Third, nuclear technology has little spillover potential into new use opportunities—it only offers a final solution for reaping civil or military benefits from fission.

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[13] Franklin C. Gowen, “Nuclear Safeguards Discussions,” Cable, Department of State, 5 August 1955, DNSA # NN00029.
[14] Glenn Seaborg to McGeorge Bundy, enclosing summary of “Nth Country Evaluation,” United States Atomic Energy Commission, 22 November 1965, *Wilson Center Digital Archive (WCDA)*, https://digitalarchive.wilsoncenter.org/document/115375.
[15] Jessica R. Lovering, Arthur Yip, and Ted Nordhaus, “Historical Construction Costs of Global Nuclear Power Reactors,” *Energy Policy* 91 (April 1, 2016): 371–82, https://doi.org/10.1016/j.enpol.2016.01.011.
[16] R. Scott Kemp, “The End of Manhattan: How the Gas Centrifuge Changed the Quest for Nuclear Weapons,” *Technology and Culture* 53, no. 2 (May 17, 2012): 272–305, https://doi.org/10.1353/tech.2012.0046.
[17] Diane Cardwell and Jonathan Soble, “Westinghouse Files for Bankruptcy, in Blow to Nuclear Power,” *The New York Times*, March 29, 2017, https://www.nytimes.com/2017/03/29/business/westinghouse-toshiba-nuclear-bankruptcy.html.

The isolation of nuclear technology decreases the security risks associated with monitoring and verification measures. Although intrusive inspections create concerns about espionage and sometimes even sabotage, these threats are confined within the four-corners of the nuclear program itself. In 1955, for instance, Washington anticipated that inspecting civil nuclear programs would only present countries with "difficult problems involving proprietary information and trade secrets" about their atomic energy assets.[18] Along these lines, West German officials worried in 1967 that the Soviets would send inspectors "to carry out industrial espionage in the Western non-nuclear countries in regard to nuclear technology." But Bonn made no mention of general security risks from inspections beyond the civil nuclear program.[19] More recently, an Iranian lawmaker suggested that inspections were linked to "sabotage and infiltration," but only of nuclear facilities.[20] As the limited scope of these concerns makes clear, states recognize that nuclear inspectors are unlikely to gather sensitive information about nonnuclear industrial assets or military capabilities at large.

Observing the details of an atomic energy program provides little insight into a state's capacity to field force beyond the nuclear realm. Gaining total access to nuclear facilities, for example, is unlikely to illuminate broader metrics of military power, such as the quantity and quality of conventional weapons, the location of military facilities, or the size and wealth of the populace. Instead, inspections reveal information about nuclear latency—the narrow capacity to build atomic weapons that lingers within the fuel cycle. This technical data can improve an adversary's war plans to target nuclear facilities in a future conflict. Yet many states have seen it as beneficial to help their adversaries estimate nuclear latency. During the peak of the Cold War, for instance, West Germany kept its civil nuclear capabilities out in the open to dampen preventive war risks with the Soviet Union. Inspections enabled Moscow to verify that Bonn was not building the bomb in secret, which decreased incentives to attack the German atomic energy enterprise.[21] Given the isolation of nuclear technology, states can let adversaries inspect their atomic weapons potential without revealing vulnerabilities in broader aspects of latent power.

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[18] Smith, "Observations on the Problem."

[19] Thomas L. Hughes to the Secretary, "Reasons for West German Opposition to the Non-Proliferation Treaty," Research Memorandum, Department of State, 1 March 1967, *WCDA* https://digitalarchive.wilsoncenter.org/document/134069. See also Susanna Schrafstetter and Stephen Twigge, *Avoiding Armageddon: Europe, the United States, and the Struggle for Nuclear Non-Proliferation, 1945-1970* (Westport, CT: Praeger, 2004), 183.

[20] Ronen Bergman, Rick Gladstone, and Farnaz Fassihi, "Blackout Hits Iran Nuclear Site in What Appears to Be Israeli Sabotage," *The New York Times*, April 11, 2021, sec. World, https://www.nytimes.com/2021/04/11/world/middleeast/iran-nuclear-natanz.html.

[21] This point was reaffirmed in many of the declassified U.S. intelligence reports on Germany's nuclear program throughout the 1960s. See for example Hugh S. Cuming, Director, Office of Intelligence and Research, to Secretary of State, "Growing Revelation of West German Interest in Nuclear Striking Force in Europe," 18 February 1960, *WCDA*, https://digitalarchive.wilsoncenter.org/document/177743; Memorandum, "German Attitudes on Nuclear Defense Questions," U.S. Embassy Bonn, 20 October 1965, *DNSA*, https://nsarchive.gwu.edu/sites/default/files/documents/4415101/Document-06-U-SEmbassy-West-Germany-memorandum.pdf.

Outcomes

Agreements with high transparency measures (intrusive inspections). Since nuclear technology is isolated but indistinguishable, our theory expects arms control to be viable when states can reach narrow scope deals with high transparency measures. The outcome of four major efforts to inhibit nuclear proliferation with formal agreements from 1968 to 2015 lends strong support for this hypothesis (H3).

First, the Treaty on the Non-Proliferation of Nuclear Weapons (1968) set the multilateral foundation to prohibit the military uses of nuclear technology. This agreement was narrow in scope and mandated intrusive inspections of civil nuclear facilities. Nonnuclear weapon signatories would only commit themselves "not to manufacture or otherwise acquire nuclear weapons."[22] William Foster, the lead American negotiator, admitted that it was "not possible" to formulate a more "comprehensive definition" of prohibited activities or technologies.[23] The entire nuclear fuel cycle was left open as a permitted activity, so long as states allowed the IAEA to verify peaceful uses. American diplomats saw these inspections as a "key element in the effort to curb nuclear proliferation," and pushed hard to make them "mandatory" in the treaty text.[24] "The treaty would be ineffective in many countries without safeguards," a senior US official argued in 1967. "The location of nuclear facilities can often be ascertained by unilateral means, but *what goes on in those facilities is usually impossible to determine without inspection*. We believe safeguards on peaceful nuclear facilities are an effective and essential verification means." The treaty would therefore help Washington better estimate nuclear latency around the world, and promised "to produce the first inspections of nuclear facilities behind the Iron Curtain."[25] Nonnuclear weapon states accepted intrusive inspections because granting the IAEA access presented minimal risk to broader military capabilities. To further allay suspicions about industrial espionage, President Lyndon Johnson offered to place all US peaceful nuclear facilities under IAEA inspection.[26] The high levels of transparency in the final agreement helped states determine whether declared atomic energy facilities were being used to acquire nuclear weapons.

Second, the Nuclear Suppliers Group (1974) created a cartel-like agreement to manage the nuclear marketplace. Given the narrow scope of prohibited activities in the NPT, a small group of nuclear supplier nations met in the early 1970s to specify which items should be permitted in aboveboard trade. Yet participants struggled to deal with

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[22] United Nations, Office for Disarmament Affairs, "Treaty on the Non-Proliferation of Nuclear Weapons (NPT)," Article II, 1968, https://www.un.org/disarmament/wmd/nuclear/npt/text.
[23] William Foster, Testimony, *Nonproliferation Treaty: Hearings Before the Committee on Foreign Relations, United States Senate, Ninetieth Congress, Second Session, on Executive H. 90th Congress, July 1968.*
[24] Cable to U.S. Embassies in Canada, United Kingdom, Italy, et al., "Non-Proliferation Treaty Safeguards Article," Department of State, 30 January 1967, *NSA EBB 253*, https://nsarchive2.gwu.edu//nukevault/ebb253/doc03.pdf
[25] Philip J. Farley, "Safeguards Provision of NPT," Memorandum, Department of State, 5 December 1967, *DNSA* #NN02095, emphasis added.
[26] Nicholas de Katzenback, "NPT," includes text of letter from Chancellor Kurt Kiesinger to President Lyndon Johnson, Department of State, 11 December 1967, *DNSA* #NN02099.

nuclear fuel cycle technology because it fell in a “grey zone” between purely peaceful and military uses. This issue took on greater weight after India extracted plutonium from an ostensibly civilian fast breeder reactor to fuel its first nuclear test in 1974. In response, American diplomats “pin-pointed enrichment, heavy water supply and reprocessing as the three most sensitive areas of the fuel cycle” that needed to be restricted on a “grey list” for suppliers.[27] Other nations refused to accept formal limitations over this broader range of technology. Instead, the final guidelines “only called for suppliers to exercise ‘restraint’ on the provision of sensitive ENR technology,” which kept the scope of the agreement fairly limited.[28] On the transparency front, the NSG founders agreed to make all exports of civil nuclear technology conditional on the recipient nation accepting international safeguards—a move designed to bring nuclear programs in NPT holdout nations under inspections.

Third, the Additional Protocol (1997) enabled the IAEA to gather greater amounts of information as violators became proficient at hiding military activities. This supplemental agreement built on the transparency baseline set in the NPT to uncover hidden nuclear weapons programs. The ability to distinguish between peaceful and military activities improved as proliferators pursued distinct “hiding” strategies. But the detection capacity needed to observe military activities in the first place increased as some states developed an aptitude for masking nuclear facilities altogether—the exposure of Iraq's nuclear weapons program in the early 1990s drove this point home. With backing from the United States and other sheriffs of the nonproliferation regime, the IAEA pushed states to accept the Additional Protocol because it gave inspectors more intrusive tools for detecting clandestine nuclear activities. Yet even this expanded menu of verification measures was confined to assets within a nuclear “site”—spot checks of conventional military facilities with more integrated technology lay beyond the scope of the deal.[29]

Fourth, country specific nonproliferation deals with North Korea (1994) and Iran (2015) were designed to limit narrow nuclear capabilities under intensive verification measures. In both instances, the agreements focused on curbing nuclear fuel cycle capabilities instead of broader strategic assets, such as ballistic missiles or other power projection capabilities. Under the terms of Agreed Framework, North Korea consented to freeze and eventually dismantle its plutonium production facility. Pyongyang's cooperation with special inspections from the IAEA seemed sufficient for the United States and its partners to verify compliance with the narrow agreement. The Joint Comprehensive Plan of Action (JCPOA) with Iran went even further on the transparency front, putting in place one of the most intrusive monitoring and verification regimes ever devised for verifying nonproliferation obligations. Yet the Iranians refused to consider any limitations beyond the four-corners of their nuclear program.

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[27] Quoted in Isabelle Anstey, “Negotiating Nuclear Control: The Zangger Committee and the Nuclear Suppliers’ Group in the 1970s,” *The International History Review* 40, no. 5 (October 20, 2018): 986, https://doi.org/10.1080/07075332.2018.1449764.

[28] Anstey, 989. See also William Burr, “A Scheme of ‘Control’: The United States and the Origins of the Nuclear Suppliers’ Group, 1974–1976,” *The International History Review* 36, no. 2 (March 15, 2014): 252–76, https://doi.org/10.1080/07075332.2013.864690.

[29] James Acton with Carter Newman, “IAEA Verification of Military Research and Development,” Vertic Research Reports, July 2006, http://www.vertic.org/media/assets/Publications/VM5.pdf, 17.

Theory Support: Strong for H3. The nuclear case supports the theory. In addressing a dual use technology which is highly indistinguishable but relatively isolated, the NPT focused on a narrow scope of the technology and employed high degrees of transparency, as predicted by H3. Many scholars argue that the most powerful states in the international system faced strong mutual incentives to inhibit the spread of nuclear weapons in the 1960s.[30] As a result, the superpowers colluded to establish the 1968 Nuclear Nonproliferation Treaty (NPT) and even coerced non-nuclear weapon states (NNWS) into joining this multilateral institution.[31] Others show that savvy NNWS wrested concessions from Washington or Moscow in exchange for NPT accession.[32] Yet these accounts miss how the dual use nature of nuclear technology enabled such arms control bargains.[33] The difficulty of distinguishing military from peaceful endeavors in the nuclear realm saddled the NPT with detection problems.[34] However, we find that states were willing to allow intrusive inspections of nuclear facilities precisely because this niche technology created manageable security risks from information disclosure. Follow-on agreements after the NPT continued to address issues around defining the limited scope and need for adequate monitoring. Agreements to limit nuclear proliferation suggest that cooperation in the nuclear space continued to be possible, though challenging. States used deals such as the Additional Protocol to address needs for even better detection in the wake of violations and bilateral agreements with individual states to curb nascent nuclear weapons programs while continuing to allow civilian nuclear development.

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[30] See Hal Brands, "Non-Proliferation and the Dynamics of the Middle Cold War: The Superpowers, the MLF, and the NPT," *Cold War History* 7, no. 3 (August 2007): 389–423, https://doi.org/10.1080/14682740701474857; Francis J. Gavin, *Nuclear Statecraft: History and Strategy in America's Atomic Age* (Ithaca, NY: Cornell University Press, 2012).
[31] Andrew J. Coe and Jane Vaynman, "Collusion and the Nuclear Nonproliferation Regime," *The Journal of Politics* 77, no. 4 (October 1, 2015): 983–97, https://doi.org/10.1086/682080; Nicholas L. Miller, *Stopping the Bomb: The Sources and Effectiveness of US Nonproliferation Policy* (Ithaca: Cornell University Press, 2018); Rebecca Davis Gibbons, *The Hegemon's Tool Kit: US Leadership and the Politics of the Nuclear Nonproliferation Regime* (Ithaca, NY: Cornell University Press, 2022).
[32] Susanna Schrafstetter and Stephen Twigge, *Avoiding Armageddon: Europe, the United States, and the Struggle for Nuclear Non-Proliferation, 1945-1970* (Westport, CT: Praeger, 2004); Tristan A. Volpe, *Leveraging Latency: How the Weak Compel the Strong with Nuclear Technology* (New York: Oxford University Press, 2023).
[33] One exception is Reid B. C. Pauly, "Deniability in the Nuclear Nonproliferation Regime: The Upside of the Dual-Use Dilemma," *International Studies Quarterly*, May 19, 2021, https://doi.org/10.1093/isq/sqab036.
[34] See Matthew Fuhrmann, *Atomic Assistance: How "Atoms for Peace" Programs Cause Nuclear Insecurity* (Ithaca, NY: Cornell University Press, 2012).

Railcar

Technology Definition

Railcars are weapon platforms when they host artillery and mortars weapons for direct (target within the sight line of the operator) or indirect (target not within the sight range of the operator) fire. This platform is referred to as a "railway gun." The technology was developed to offer mobility to increasingly larger pieces of artillery—many of these early weapons were repurposed naval armaments. Railway guns can be considered to take the form of either direct fire weapons on armored trains or large indirect fire weapons on rail cars. As the weapon platform is tied to the availability of properly gauged railroad tracks, over time the preponderance of this platform took the form of increasingly larger caliber weapons that fired indirectly. Unlike field artillery platforms, this weapon system had no civilian applications and was eventually replaced by aircraft delivered ordnance and missiles.

Time Period Boundaries

We code the debut of modern railway guns around the heavy use of these systems during the First World War in 1914. However, an early version of the technology emerged in 1862 when Confederate (CSA) forces in the American Civil War first developed this weapons platform. During the Peninsula Campaign, CSA forces mounted a 32-pounder Brooke naval rifle to a rail car protected by iron casemates and engaged in artillery duels with Union forces. Later in the war, at the siege of Petersburg in 1864, Union forces mounted a thirteen-inch seacoast mortar to a rail car and indirectly fired 218-pound shells on CSA forces at ranges of up to two-plus miles.[1] Aside from experimentation by the French during the siege of Paris in 1870 and British Naval Captain John Fisher in 1881 and 1882, this technology did not advance until the late 19th and early 20th century.[2]

In the late 19th century France began to experiment with mounting howitzers from 155mm to 320mm on rail cars. Germany and the Austro-Hungarian Empire also secretly developed 305mm and 420mm variants. The limitations of Europe's road networks and French experimentation on this system drove German investment and development.[3] The First World War saw the operational usage of railway guns by the Germans, French, British, and Americans. By the end of the war these weapons systems were

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[1] Jack H. McCall, Jr., "When Railroad Guns Ruled," *MHQ: The Quarterly Journal of Military History* 21, 1 (Autumn 2008): 74. See also, F. Stansbury Haydon, "Confederate Railroad Battery at Jacksonville, Florida, March 1863, not the First Use of Railway Ordnance in the United States," *The Journal of the American Military Foundation*, Vol. 2, No. 4 (Winter, 1938): pp.229-234.

[2] Ibid.

[3] Ibid. See also, David Stevenson, "The Field Artillery Revolution and the European Military Balance, 1890–1914," *The International History Review* 41, No. 6 (2019): 1301-1324,

viewed as the best way to employ very large caliber artillery.[4] The German "Big Bertha" 420mm gun, for instance, could fire light projectiles up to 68 miles.[5]

The inter-war period saw railway guns maintained by the United States and Britain. The Soviets used them in its war with Finland, and Germany, while prohibited to have offensive weapons under the terms of the Treaty of Versailles, experimented secretly on them until Hitler renounced the limitations of the treaty.[6] And during the Second World War the Wehrmacht used 12 different varieties ranging from 150mm to 800mm.[7] But by the end of the war the massive size of these weapon systems, their cumbersome logistics, and their vulnerability to attack from the air made them obsolete.[8] We therefore code the obsolesce of the technology at 1945.

In the age of ballistic missiles, there has been discussion of, and experimentation on, placing nuclear missiles on railcars. This has nothing to do with railroad guns—it would be an extension of mobile missile launch platforms (such as transporter erector launchers that fall under the rocket technology category).[9]

Railcars [Railway Guns], 1914–1945

Distinguishability: <u>High</u>

Railway guns were highly distinguishable from their closest civilian cousin—the railcar—for four reasons.[10] First, the physical features of railway guns were large and distinct compared to normal railcars. The most obvious indicator was the artillery piece mounted atop the wagon, which was difficult to obscure. In addition, the wagon itself needed to be specially built or extensively modified to secure the heavy gun mount. Many railway guns also required considerable support materials and mobile infrastructure to fire, which further set them apart from non-weapon platform railcars. Second, railway guns had to be specifically developed to address unique issues related to aiming the gun (method of traverse) and absorbing recoil force (horizontal and vertical). Many recoil systems required custom railcar wagons. Others relied on bespoke anchorage techniques to transfer the vertical force from the gun into the ground, such as a building

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[4] Ibid.: 75-6. See also, Konrad F. Schreier, Jr., "Admiral Plunkett's Railway Battle Fleet," *Railroad History* No. 158 (Spring 1988): 94-102.
[55] Ibid., 76. See also, Stephen F. Hurst, "The Biggest Gun in the World," *Military History* (January/February 2007): 50-3.
[6] Ibid, 78.
[7] Ibid., 79.
[8] Ibid.
[9] See, for example: Barry E. Fridling and John R. Harvey, "On the Wrong Track? An Assessment of MX Rail Garrison Basing," *International Security* 13, No. 3 (Winter, 1988-1989): 113-141, and, Alan Cunningham, "How Useful Is North Korea's Railroad Missile Launching System?," *The Diplomat* (November 19, 2021).
[10] This section draws heavily from the specific features of railway guns detailed in a post–World War I report by the US government, see H.W. Miller, "Railway Artillery: A Report on the Characteristics, Scope of Utility, of Railway Artillery," Ordnance Department, Government Printing Office, 1921. See also Fred Westing, *The Locomotives That Baldwin Built* (Bonanza Books, 1966); Marc Romanych and Greg Heuer, *Railway Guns of World War I* (Osprey Publishing, 2017).

platforms or support structures on either side of the wagon. Of course, civilian railcars did not need to follow these design requirements. Third, the deployment of railway guns revealed intended use because many such platforms travelled with extensive support capabilities and needed to take clear steps to aim and stabilize the gun. The manpower requirements were high, with some requiring more than 1000 personnel to fire and maintain very large guns. Many railway guns were also much heavier than non-weapon wagons, so these trains often had to move slowly along railways designed to bear lighter loads. Fourth, the conversion speed from a normal railcar into a railway gun also became quite slow by the modern debut of the weapon platform in the First World War. Again, typical railcars could not handle the recoil force from these mounted weapons, which made it faster to simply design and build a railgun wagon from scratch.

Integration: <u>High</u> (Military) / <u>High</u> (Civilian)

On the military side, railway guns enjoyed a brief period of high integration in the early-20th century before being supplanted by air and rocket standoff weapons. Much like field artillery, railway guns were used to perform a variety of indirect and direct fire missions. At the start of the First World War, the weapon platform helped the French move large static ground and naval guns to the battlefield front.[11] The belligerents in the conflict quickly developed new railway gun systems to increase the mobility of very large artillery pieces. As these platforms matured, the size and range of munitions made them uniquely suited for bombardment of civilian populations (such as firing on Paris) or deep strike in preparation for ground invasion.[12] Strategic air bombing replaced the importance of this role for railroad guns. Marginal costs varied widely over time, but the systems were generally cost effective.[13] In terms of spillover, the railroad gun was largely a stand-alone innovation. The size and range of the weapons increased, but they did not serve as a driver of other technologies.

Railway guns were exclusively a military-only technology. The purposes of this weapons system, as discussed above, had no civilian equivalents. Both civilians and military forces have used railroads for transportation of people and supplies, but only the military used railway guns. However, we consider the closest cousin to this weapon platform—railcars—when coding the level of civilian integration during this period. Railcars have been used extensively within civilian economies around the globe. The technology reached its peak ubiquity during the early-20th century, offering a wide range of commercial transportation functions, many of which remain to service today. The cost of developing and using railcars was also quite modest compared to many alternative transportation methods, especially during the brief halcyon era for railway gun platforms.[14]

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[11] Ian V. Hogg, *Allied Artillery of World War One* (Crowood, 1998).
[12] See Romanych and Heuer, *Railway Guns of World War I*; Steven J. Zaloga, *Railway Guns of World War II* (Osprey Publishing, 2016).
[13] See Schreier, "Admiral Plunkett's Railway Battle Fleet."
[14] See Kate McDonald, "Asymmetrical Integration: Lessons from a Railway Empire," *Technology and Culture* 56, no. 1 (2015): 115–49, https://doi.org/10.1353/tech.2015.0035; Patrick O'Brien, *Railways and the Economic Development of Western Europe, 1830-1914* (Oxford: Palgrave Macmillan, 1983); Christian

Outcomes

<u>Agreement imposed on defeated power</u>. In the wake of the First-World War, the Versailles Peace Treaty imposed strict armament control rules on Germany.[15] These terms put limits on artillery, including railway guns. Germany was limited to maintaining 204 77mm guns with 1000 shells per gun and 84 105mm guns with only 800 rounds per weapon.[16] This outcome lends neutral support for our expectations about H4 because the role of technology is difficult to isolate in this case where post-war armament controls were imposed on defeated nation. The Treaty of Versailles imposed intrusive inspections to verify controls and bans over many military technologies—Germany had little choice but to accept these provisions. In the years after Versailles, the absence of arms control agreements over railway guns also appeared to be the result of the technology becoming obsolete relative to modern standoff and strategic bombing capabilities.

Theory Support: <u>Neutral for H4</u>.

Wolmar, *Railways and The Raj: How the Age of Steam Transformed India* (London: Atlantic Books, 2017).

[15] For the full text, see Peace Treaty of Versailles, https://net.lib.byu.edu/~rdh7/wwi/versa/versa4.html.

[16] *Treaties and Other Agreements of the United States of America, 1776-1949, Volume 2 Multilateral 1919-1930*, compiled under the direction of Charles I. Bevans, LL.B. (Washington, DC: Department of State Publication 8441, released 1969: 123.

Rockets

Technology Definition

Rockets are projectiles which derive thrust from engines or motors powered by onboard propellant.[1] Rockets that travel to altitudes of 80km or higher can be thought of as space capabilities. Nearly all types of intermediate and long range (intercontinental) ballistic missiles are able to reach space, even if they do not do so in their typically employed operational trajectories. Rockets used as missiles vary in size, though they are based on similar technical principles. Intercontinental ballistic missiles (ICMBs) are on a suborbital trajectory, while short range missiles stay within the Earth's atmosphere.[2] Although our definition focuses on these long-range platforms, we briefly consider shorter range rockets as well.

All space-launch vehicles (SLV) are also a form of rocket, and these typically carry a payload, such as a satellite, to space. While the technology has continued to evolve, the basic principle of rocket launch has been the same since the 1940s. Missiles and SLVs are very similar technologies at the lift stage and differ primarily in the angle of launch and speed. There are further differences once payload separates from the rocket; SLV payloads are intended to enter orbit while a missile payload (a warhead) re-enters the atmosphere to go to its intended target.[3]

All rocket systems generally include motors, propellants, air frames, navigation and guidance, stage and payload separation, and telemetry. SLV and missiles differ in how they handle reentry, trajectories, and other operational practices such as launch preparation.[4] Rocket technology is dual use; it can be a weapon or a vehicle for science and exploration.

Time Period Boundaries

The earliest capabilities classified as rockets appeared in 1944 with the German V2 missile. The primary early developments occur in the US and USSR. For the first part of

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[1] Modern use of rockets stems for both missiles and space launch stem from the first ballistic missile, the V-2, developed in Germany during WWII. See James Clay Moltz, *The Politics of Space Security: Strategic Restraint and the Pursuit of National Interests* (Stanford, CA: Stanford Security Studies, 2008), 69–70.

[2] See Kelsey Davenport, "Worldwide Ballistic Missile Inventories," Fact Sheets and Briefs, Arms Control Association, December 2017, https://www.armscontrol.org/factsheets/missiles.

[3] For an overview of the dual use nature of rockets and space launch vehicles, see James Clay Moltz, *Crowded Orbits: Conflict and Cooperation in Space* (New York, NY: Columbia University Press, 2014), 11–19, https://doi.org/10.7312/molt15912; Joan Johnson-Freese, *Space as a Strategic Asset* (New York, NY: Columbia University Press, 2007), 27–50.

[4] Michael Elleman, "Reducing the Risk of Iran Developing an ICBM" (London: The International Institute for Strategic Studies, July 31, 2018), 6, https://www.iiss.org/blogs/research-paper/2018/07/reduce-risk-iran-develop-icbm-nuclear; Brian Weeden, "A Space Launch Vehicle by Any Other Name…," The Space Review, March 9, 2009, https://www.thespacereview.com/article/1323/1.

rocket development in the US and USSR, missiles and SLVS were not distinguishable. In the mid-1960s, however, the trajectories of civilian and military applications of rockets started to diverge. Although the scientific fundamentals remained similar, the design and especially deployment patterns for military missiles began to differ from civilian space launch capabilities. We divide the case into two time periods: (1) 1940–1970 and (2) 1970–2020.

Rockets, 1944–1970

Distinguishability: <u>Low</u>

In the early period of in the space age, from 1944 to 1970, missiles and SLVs used the same exact rockets or “boosters” to reach space, and distinguishability was low. The difference between civilian space research and military missile developments was largely in the payload that a rocket would launch. However, the development pathway for civilian space launch rockets was closely intertwined with military missile programs in both the United States and Soviet Union. As a US National Intelligence Estimate concluded in December 1962, the Soviet space and missile programs "used the same boosters and launching facilities, and are mutually supporting in other respects as well."[5] The NIE quoted a prominent Soviet scientist who claimed that, "We have no distinction between military and civilian [space] projects."[6] After the missile arms race between Washington and Moscow intensified in 1955, US officials directed resources away from the development of rockets intended for the purpose of launching scientific satellites into orbit. This meant that subsequent civilian efforts had to repurpose rockets “derived from designs of defunct weapons systems,” Joan Johnson-Freese finds, noting that, “The early Mercury space capsules, for example, were lifted into orbit using modified Atlas ICBM launchers.”[7] Indeed, both the United States and Soviet Union used the same facilities for testing both missiles and SLVs. The first Soviet satellite, Sputnik I, launched October 4, 1957, used a modified Soviet R-7 intercontinental ballistic missile for launch. The R-7 had become operational as a weapon delivery system in August 1957.[8] Soviet tests and launches for both applications took place at the Baikonur Cosmodrome. The Americans likewise designed several generations of early space-launch vehicles based on ballistic missiles, testing both capabilities at Cape Canaveral Air Force Station.[9]

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[5] Director of Central Intelligence, "The Soviet Space Program," National Intelligence Estimate No. 11-1-62, Central Intelligence Agency, December 5, 1962, *DNSA*, 9, https://nsarchive2.gwu.edu//NSAEBB/NSAEBB501/docs/EBB-05.pdf.
[6] Director of Central Intelligence, "The Soviet Space Program," 10.
[7] Johnson-Freese, *Space as a Strategic Asset*, 44.
[8] Walter A. McDougall, *The Heavens and the Earth: A Political History of the Space Age* (New York: Basic Books, 1985), 61, 277; Moltz, *The Politics of Space Security*, 71–123.
[9] Burrows, *This New Ocean*, 206–9; McDougall, *The Heavens and the Earth*, 153. The Americans launched their first successful satellite using the Juno I rocket, a derivative of the Redstone short range ballistic missile. The Juno II rockets used for satellite launches were based on the PGM-19 Jupiter, the

In the 1960s, rocket development and deployment began to diverge somewhat, with rockets for civilian space flight launched out of Cape Canaveral while the military testing moved to Vandenberg Airforce Base. The most extensively used SLV continued to employ a modified version of the Thor ballistic missile as the first stage booster.[10] The early period launch method—via a surface launch pad—was also similar for both SLVs and ballistic missiles. In the mid-1960s, the US shifted away from vertical above-ground launch for missiles, moving instead to hardened silos.[11] These actions set the stage for a major shift in distinguishability starting in 1970.

Integration: Low (Military) / Low (Civilian)

Long-range rockets exhibited low integration during this period for multiple reasons. First, the range and variety of uses for the technology were limited to strategic nuclear and intelligence missions on the military side (e.g., ICBMs and satellite delivery) and peaceful exploration of space (e.g., Project Mercury) within the civilian realm.[12] For the United States and Soviet Union, ICBMs played a niche but hugely significant role in the strategic nuclear mission set.[13] Second, long-range rockets were developed and deployed in relative isolation away from other military capabilities and even civilian research. Within the military, ICBMs were often operated in their own units and divisions. On the civilian side, the development of space launch vehicles was largely government-funded and conducted by a few labs focused on this issue. For example, NASA managed and funded civilian applications of space launch technology in the United States.[14] Long-range rocket technology was also incredibly expensive to produce during this period.[15] Putting aside research and development expenditures, the operational Titan II ICBM platform, for example, cost $20.7 million for each missile, $78 million for each hardened missile site, with an annual operating cost of $18 million per site (2022 US dollars).[16]

However, one key qualification is in order: ballistic missiles at intermediate and low ranges were more likely to be deployed with other military units and collocated with other capabilities. In comparison to their nuclear-tipped ICBM brethren, shorter range

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first nuclear-tipped medium-range ballistic missile. The next generation of launch vehicles was based on the Thor ballistic missile.

[10] The last derivative of the Thor missile family, the Delta II booster, was retired in 2018.

[11] For a detailed overview, see John C. Lonnquest and David F. Winkler, "To Defend and Deter: The Legacy of the United States Cold War Missile Program" (Washington, DC: Department of Defense Legacy Resource Management Program, 1996).

[12] Burrows, *This New Ocean*, 206–9; Johnson-Freese, *Space as a Strategic Asset*, 42–47.

[13] Asif A. Siddiqi, *Sputnik and the Soviet Space Challenge* (Gainesville, FL: University Press of Florida, 2003); Moltz, *The Politics of Space Security*, 69–123.

[14] Johnson-Freese, *Space as a Strategic Asset*, 51–81; McDougall, *The Heavens and the Earth*, 157–76.

[15] On the early costs, see Sean N. Kalic, *US Presidents and the Militarization of Space, 1946-1967* (College Station: Texas A&M University Press, 2012); McDougall, *The Heavens and the Earth*, 97–111; Siddiqi, *Sputnik and the Soviet Space Challenge*, 205.

[16] "Titan II History," Titan Missile Museum, (Accessed May 12, 2022), https://titanmissilemuseum.org/about/titan-ii-history/.

missiles performed a wider variety of military missions and saw greater use on the battlefield, in part because they were generally cheaper to develop and deploy.[17]

Outcomes

Agreements considered but rejected on detection grounds. During the 1960s, the United States and the Soviet Union discussed a freeze on the production of delivery vehicles for nuclear and conventional warheads. However, no agreement was reached. Early attempts to limit missiles stumbled on the challenge of observing compliance and focused on a narrow set of capabilities but still failed to achieve an agreement. Prior to the deployment of surveillance satellites, the United States and the Soviet Union lacked the means to unilaterally observe even exclusively military capabilities, much less differentiate between civilian and military tests and launches. The Soviet Union opposed any intrusive monitoring measures and also sought to avoid limits in an area where it assessed that its comparative disadvantage would soon be replaced by parity.

In 1964, the United States supported the Freeze proposal in the Eighteen Nation Committee on Disarmament (ENCD) at the United Nations.[18] The idea was to freeze US and Soviet levels of ICBMs, MRBMs, bombers, and missile defense systems at their current levels. The proposals called for extensive on-site inspections of weapons in the territory of the adversary. Both parties would have to declare both missile and space booster production facilities, give notice of space booster production plans, provide notification of all launches (with on-site observation of the vehicle prior to launch), and provide plans for the use of each space launch booster to guard against the possibility of these capabilities being stockpiled and available for conversion into military missiles. According to this plan, all production of space boosters would be allowed to proceed without limits, but would be monitored to check that only permitted civilian activities were conducted.[19] The Soviet Union rejected the idea of inspection; there were also signs that the Americans would not have implemented their own proposal either.[20]

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[17] For systematic assessments on the evolution of missile capabilities in this context, see Bryan R. Early, “Exploring the Final Frontier: An Empirical Analysis of Global Civil Space Proliferation,” *International Studies Quarterly* 58, no. 1 (March 1, 2014): 55–67, https://doi.org/10.1111/isqu.12102; Simon A. Mettler and Dan Reiter, “Ballistic Missiles and International Conflict,” *Journal of Conflict Resolution* 57, no. 5 (October 1, 2013): 854–80, https://doi.org/10.1177/0022002712453702.

[18] President Johnson’s message of January 21, 1964, to the Eighteen-Nation Disarmament Committee in Geneva, *The American Presidency Project*, https://www.presidency.ucsb.edu/documents/message-the-18-nation-disarmament-conference-geneva.

[19] McGeorge Bundy, "A Missile Launcher Freeze Proposal for the President's State of the Union Message," Memorandum for the President, December 28, 1965, Record Group 59 PolMil, National Archives, College Park, MD; "Draft US Proposals for a Freeze and Reduction of Strategic Nuclear Delivery Vehicles (SNDVs)," Talking Paper for use by Colonel Thomas St. J. Arnold, March 2, 1966, Record Group 59 PolMil, National Archives, College Park, MD.

[20] Circular Airgram From the Department of State to Certain Posts, "Recent Developments in Strategic Forces," Washington, December 31, 1966, *Foreign Relations of the United States (FRUS)*, 1964–1968, Volume X, Doc. 163, https://history.state.gov/historicaldocuments/frus1964-68v10/d163. On the broader context of these proposals within other efforts to establish détente, see Moltz, *The Politics of Space Security*, 124–46; Kalic, *US Presidents and the Militarization of Space, 1946-1967*, 77.

Internally, US policymakers questioned the provisions which US negotiators, at least for the time being, were supporting publicly in the UN. For example, US officials noted that a ban on re-entry vehicles could be verified using inspections, but this "might disclose sensitive US information on warhead or penetration aid characteristics."[21] It was thus decided internally among US officials that inspection of these kinds of production facilities would not be in the US interest.

Theory Support: <u>Strong for H3.</u> States considered but ultimately did not come to an agreement, due in significant part to not being able to address detection challenges. Options with intrusive monitoring were considered but ultimately rejected. The effort failed in large part because rocket technology was still plagued by dual use indistinguishability. The recent launch of spy satellites enabled the superpowers to observe rocket capabilities—a key US National Intelligence Estimate (NIE) from 1962 revealed that "the major facilities involved in the Soviet space [launch] program have been identified."[22] But differentiating these civilian capabilities from military ICBMs presented a major challenge. The problem was that "the USSR's space program has been closely linked to its military," the NIE underscored: "The two programs have used the same boosters and launching facilities, and are mutually supporting in other respects as well."[23] This created an insurmountable detection challenge in negotiations. The Americans called for extensive on-site inspections of both military ICBM *and* civilian SLV facilities to verify compliance with its missile freeze proposal.[24] The Soviets rejected these inspection provisions. The discussions ended in failure.

Rockets, 1970–2020

Distinguishability: <u>High</u>

In 1970, the trajectories of civilian and military applications of rockets started to diverge in ways that made them significantly more distinguishable, even while scientific and engineering fundamentals remained similar. The main drivers behind this shift were differences in deployment and launch patterns between space launch vehicles (SLVs) and ICBMs. For the American and Soviet space programs, SLVs grew into larger platforms capable of lifting heavier payloads into space, continued to rely on liquid fuel, and were launched from well-known sites with extensive support infrastructure. In the

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[21] United States Arms Control and Disarmament Agency, "Statement to the ENDC on Verification of a Freeze on Strategic Nuclear Vehicles," Memorandum to Members of the Committee of Principals, July 24, 1964, Record Group 59 PolMil, National Archives, College Park, MD.
[22] Central Intelligence Agency, "The Soviet Space Program," National Intelligence Estimate No. 11-1-62, December 5, 1962, *National Security Archive (NSA)*.
[23] "The Soviet Space Program," NIE 1962.
[24] McGeorge Bundy, "A Missile Launcher Freeze Proposal for the President's State of the Union Message," Memorandum for the President, 28 December 1965, *National Archives (NA)* in College Park, MD, Record Group 59 PolMil.

earlier time frame, both military and civilian rockets had been launched from above-ground launch pads, but from 1970 onward, ballistic missiles were deployed in hardened silos in remote locations or on mobile transporter erector launchers (TELs).[25] The introduction and greater use of mobile missiles increased distinguishability because these military capabilities were deployed on TELs,[26] which have no applications in civilian space launch. Civilian space launch vehicles continued to be launched above ground, with days of preparation and often a wait for optimal weather conditions. Ballistic missiles were designed to launch on short notice under varying environmental conditions. Civilian SLVs were deployed at well-known locations with extensive support infrastructure for equipment and personnel. By contrast, ballistic missiles needed to be deployed in ways that maximized their survivability against an attack, including on mobile launchers, at dispersed sites, and with protective measures such as hardened silos.[27] SLVs also mostly used liquid fuel, with rockets fueled at the launch pad before launch. Ballistic missiles tended to rely on solid fuel, which was contained in the rocket and required no fueling.

The distinct deployment signatures for civilian SLV and missiles became increasingly observable to overhead satellites as intelligence capabilities improved.[28] Today, these differences are even apparent in open-source commercially available imagery. For example, SLVs are often observable on launch pads with infrastructure such as platforms, gantries, and ground-support vehicles.

Despite the sharper distinctions between military and civilian deployment, differences in production have become harder to discern in some countries. This has implications for conversion speed and may portend a future shift back toward indistinguishability. In the United States and the Soviet Union, civilian and military rocket programs developed largely in parallel rather than at the same production facilities. Conversion between one capability to the other was possible but in the direction of

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[25] For overviews, see Pavel Podvig, "The Window of Vulnerability That Wasn't: Soviet Military Buildup in the 1970s—A Research Note," *International Security* 33, no. 1 (July 2008): 118–38, https://doi.org/10.1162/isec.2008.33.1.118; Robert S. Norris and Hans M. Kristensen, "Nuclear U.S. and Soviet/Russian Intercontinental Ballistic Missiles, 1959-2008," *Bulletin of the Atomic Scientists* 65, no. 1 (January 2009): 62–69, https://doi.org/10.2968/065001008; Lonnquest and Winkler, "To Defend and Deter: The Legacy of the United States Cold War Missile Program."

[26] Hans Kristensen, "Military Might Takes Center Stage at Chinese 70-Year Anniversary Parade," *Federation of American Scientists* (blog), October 1, 2019, https://fas.org/blogs/security/2019/10/china-military-parade/.

[27] Elleman, 6. Hardened silos are also usually located in remote geographic areas; numerous silos are often present over a large area. When some former Russian R-36 ballistic missiles silos were converted for civilian space launches in in the 1990s-2000s, new supporting infrastructure was introduced above ground. See "Iridium, Frustrated by Russian Red Tape, to Launch First 10 Iridium Next Satellites with SpaceX in July," SpaceNews, February 25, 2016, https://spacenews.com/iridium-frustrated-by-russian-red-tape-to-launch-first-10-iridium-next-satellites-with-spacex-in-july/.

[28] See US Congress, *A Revitalized ACDA in the Post-Cold War World: Joint Hearing Before the Subcommittee on International Security, International Organizations, and Human Rights and International Operations of the Committee on Foreign Affairs, House of Representatives, One Hundred Third Congress, Second Session, June 23, 1994* (Washington, DC: US Government Printing Office, 1994); Frank Pabian, "Commercial Satellite Imagery as an Evolving Open-Source Verification Technology: Emerging Trends and Their Impact for Nuclear Nonproliferation Analysis," Joint Research Centre (European Commission, 2015).

missile rockets to SLV booster, which was less problematic from a monitoring standpoint. For many decades, no countries pursued conversion in the opposite direction, from SLV to missiles.[29]

But some contemporary missile programs do feature closer production ties between ICBMs and SLVs, suggesting that lower distinguishability could emerge in the future. This development pathway is more characteristic of rocket programs in countries beyond the United States and Soviet Union/Russia, notably North Korea, China, and Iran.[30] There is evidence that China's space and missile programs are more closely tied together.[31] In the case of Iran, there is some concern that the SLV capabilities could be converted into long-range ballistic missiles.[32] Even more worrisome, Iranian launcher tests in 2022 for placing a satellite into orbit and developing missile platforms both used a solid-fueled rocket.[33]

Observers have so far been able to differentiate civilian and military launches. In addition, considerable modifications would be necessary to convert an SLV to an ICBM. But the concern about using ostensibly 'peaceful' SLV programs to mask military ICBM development is certainly more plausible than in the US-USSR/Russia context. China and Iran are also the only countries that have used mobile launchers for SLVs. Though the main Iranian SLVs are thought to be not well suited for use as weapons delivery missiles,[34] this mobile launch capability, along with additional similarities in rocket design, raises further concern that developments for space launch may be quickly converted to weapons capabilities.[35] The question over whether civilian space programs can be converted or adapted for military purposes has also been raised in the India case. Analysts writing in 2011 noticed that the civilian Indian space program began to adopt a more active military stance. Analysts in 2019 mentioned the prospect of

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[29] Developments on the civilian side have informed military applications, for only a few countries. India and Israel used solid fuel motors developed for the civilian space launch program to advance their long-range ballistic missile programs. See Elleman, 7.

[30] On the maturation of North Korea's ICBM program, see Melissa Hanham and Seiyeon Ji, "Advances in North Korea's Missile Program and What Comes Next," *Arms Control Today* 47, no. 7 (2017): 6–11; Ankit Panda and Vipin Narang, "North Korea's ICBM: A New Missile and a New Era," War on the Rocks, July 6, 2017, https://warontherocks.com/2017/07/north-koreas-icbm-a-new-missile-and-a-new-era/.

[31] Brian Harvey, *China's Space Program: From Conception to Manned Spaceflight* (Berlin, DE: Springer, 2004).

[32] Fabian Hinz, "Have Iran's Space Ambitions Taken a Worrisome New Turn?," James Martin Center for Nonproliferation Studies, May 7, 2020, https://nonproliferation.org/have-irans-space-ambitions-taken-a-worrisome-new-turn/; "Open-Source Analysis of Iran's Missile and UAV Capabilities and Proliferation," (London, UK: The International Institute for Strategic Studies, April 2021).

[33] "Report: Iran Launched Solid-Fuel Satellite Rocket into Space," ABC News, January 13, 2022, https://abcnews.go.com/International/wireStory/report-iran-launched-solid-fuel-satellite-rocket-space-82245006.

[34] "Iran's Upcoming Simorgh Rocket Launch," All Things Nuclear, February 14, 2016, https://allthingsnuclear.org/lgrego/irans-upcoming-simorgh-rocket-launch/; Aaron Arnold et al., "The Iran Nuclear Archive: Impressions and Implications," *Intelligence and National Security* 36, no. 2 (February 23, 2021): 230–42, https://doi.org/10.1080/02684527.2021.1857086.

[35] Iran's Qased SLV was launched in 2020 using a mobile transporter-erector. See Fabian Hinz, "Have Iran's Space Ambitions Taken a Worrisome New Turn?," European Leadership Network, April 24, 2020, https://www.europeanleadershipnetwork.org/commentary/have-irans-space-ambitions-taken-a-worrisome-new-turn/.

converting civilian capabilities into military ones.[36] These developments should be closely watched in the years ahead for signs of rocket technology becoming less distinguishable.

Integration: Low (Military) / Low (Civilian)

The level of integration remained low in the second time period. In terms of financial requirements, ICBMs and SLVs continued to be expensive capabilities to develop and operate.[37] Even recent innovations, such as reusable SLV boosters, only offer marginal cost savings.[38] Despite the significant addition of commercial space launch applications, the range and variety of uses for long-range rockets never underwent a dramatic expansion—placing payloads into orbit or delivering warheads to targets remained the primary tasks. On the military side, ICBM silos and mobile-missile launch bases were still largely isolated and distinct from civilian or military space-launch efforts. Today, the United States and Russia separate their long-range nuclear-armed ballistic missile forces from general purpose forces, and chains of command are separate.[39] For instance, US ICBMs exist exclusively in nuclear roles on special submarines and in dedicated silos.[40] Facilities, basing, units, and deployment practices for ballistic missiles are generally separated from other military forces by most nuclear powers.[41] The processes to develop, test, and deploy other types of missiles is not integrated with ballistic missile development, testing, or deployment. For mobile missiles, the configuration of the TEL to support and deploy a ballistic missile is specialized and typically not integrated with other military capabilities. Even in cases where states might be most expected to integrate TELs with other forces, evidence suggests that is not the

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[36] James Clay Moltz, *Asia's Space Race: National Motivations, Regional Rivalries, and International Risks*, Contemporary Asia in the World (New York, NY: Columbia University Press, 2011); Mian Zahid Hussain and Raja Qaiser Ahmed, "Space Programs of India and Pakistan: Military and Strategic Installations in Outer Space and Precarious Regional Strategic Stability," *Space Policy* 47 (February 1, 2019): 63–75, https://doi.org/10.1016/j.spacepol.2018.06.003.
[37] For US government estimates of the massive costs involved with modernizing its ICBM force, see "Projected Costs of U.S. Nuclear Forces, 2021 to 2030," Congressional Budget Office, May 2021, https://www.cbo.gov/publication/57240.
[38] Michael Sheetz, "SpaceX Raises Prices for Rocket Launches and Starlink Satellite Internet as Inflation Hits Raw Materials," CNBC, March 23, 2022, https://www.cnbc.com/2022/03/23/spacex-raises-prices-for-launches-and-starlink-due-to-inflation.html.
[39] Hans M. Kristensen and Matt Korda, "United States Nuclear Weapons, 2021," *Bulletin of the Atomic Scientists* 77, no. 1 (January 2, 2021): 43–63, https://doi.org/10.1080/00963402.2020.1859865; Defense Intelligence Agency, "Russia Military Power: Building a Military to Support Great Power Aspirations" (Washington, DC: Defense Intelligence Agency, 2017).
[40] "America's Nuclear Triad," U.S. Department of Defense, accessed July 21, 2021, https://www.defense.gov/Experience/Americas-Nuclear-Triad/.
[41] This is not necessarily the case with short-range ballistic missiles, as we discuss below. There is also concern that China does co-mingles some its nuclear and conventional forces and command, control, and communications systems. This would suggest a higher degree if integration for Chinese capabilities. "Entanglement: Russian and Chinese Perspectives on Non-Nuclear Weapons and Nuclear Risks" (Washington, D.C.: Carnegie Endowment for International Peace, 2017), 4–5, 52, https://carnegieendowment.org/files/Entanglement_interior_FNL.pdf.

case. A 2014 assessment of North Korea's mobile missile launchers identified and modeled facilities with features such as large, high-bay buildings that presented visible signatures.[42]

One qualification is in order: ballistic missiles at intermediate and low ranges are more likely to be deployed with other military units and collocated with other capabilities. At lower ranges, ballistic missiles tend to be more highly integrated. For example, Russia's primary short-range ballistic missile, the Iskander-M (9M723), is distributed to 12 rocket brigades within the Russian Ground Forces. These systems have a maximum range of 500 km and carry a payload between 480 and 700 kg. They are dual-capable systems with a potential nuclear role.[43] These systems, while capable of higher altitudes, fly in a depressed trajectory that does not exceed the 80 km limit recognized by the US as the beginning of space. Depressed trajectories are common for short-range ballistic missiles and are a key reason they are not the focus of this study.

Outcomes

Agreements with a mix of verification measures. In this period, several successful negotiations produced limits on strategic missiles. Strategic arms talks (SALT I and II) and the START and New START agreements that followed all placed limits on ballistic missiles. The first set relied on intelligence capabilities to differentiate between military and civilian uses. The latter strategic treaties use inspections but did not mandate any need to access civilian space vehicle production or launch. In line with our expectations, the superpowers reached agreements with various monitoring provisions to limit the military uses of rocket and space technology. Scholars have identified several other factors responsible for the success of arms control in the 1970s. The superpowers faced mutual incentives to manage nuclear risks in the wake of the 1962 Cuban missile crisis, especially as both nations achieved parity in strategic forces.[44] These features certainly made arms control more desirable. But they cannot explain the information problems that doomed initial arms control efforts in the 1960s. Recent research argues that improvements in satellite surveillance made deals more viable by the 1970s.[45] Indeed, the superpowers could rely on these platforms to better monitor compliance. However, our results indicate that a shift in distinguishability occurred independent of

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[42] See "That Ain't My Truck: Where North Korea Assembled Its Chinese Transporter-Erector-Launchers," 38 North, February 3, 2014, https://www.38north.org/2014/02/jlewis020314/.

[43] See Hans M. Kristensen and Matt Korda, "Russian Nuclear Weapons, 2021," *Bulletin of the Atomic Scientists* 77, no. 2 (March 4, 2021): 91, https://doi.org/10.1080/00963402.2021.1885869; "SS-26 Iskander," Missile Threat, accessed July 21, 2021, https://missilethreat.csis.org/missile/ss-26-2/.

[44] Gavin, *Nuclear Statecraft*; Brendan Rittenhouse Green, *The Revolution That Failed: Nuclear Competition, Arms Control, and the Cold War* (New York, NY: Cambridge University Press, 2020); John D. Maurer, *Competitive Arms Control: Nixon, Kissinger, and SALT, 1969-1972* (New Haven: Yale University Press, 2022).

[45] Kalic, *US Presidents and the Militarization of Space, 1946-1967*; Andrew J. Coe and Jane Vaynman, "Why Arms Control Is So Rare," *American Political Science Review* 114, no. 2 (May 2020): 352–53, https://doi.org/10.1017/S000305541900073X; Aaron Bateman, "Mutually Assured Surveillance at Risk: Anti-Satellite Weapons and Cold War Arms Control," *Journal of Strategic Studies* 45, no. 1 (January 2, 2022): 119–42, https://doi.org/10.1080/01402390.2021.2019022.

improvements in monitoring technology, which effectively eliminated the dual use issue in strategic arms control negotiations. By the time of the SALT I and SALT II negotiations in the 1970s, the US stopped demanding inspections, which created greater bargaining room for both sides to achieve foundational limits over ICBMs.[46] Subsequent deals, such as the START, INF, and New START treaties, incorporated inspections to better observe specific military assets. But the dual use detection problem no longer haunted these negotiations.

States also phased out inspections to limit disclosure damage over more highly integrated missiles. The 1987 Intermediate-Range Nuclear Forces (INF) treaty between the United States and the Soviet Union/Russia banned all ground-launched ballistic and cruise missiles with intermediate ranges (500–5,500 km). In contrast to their ICBM brethren, shorter range rockets and cruise missiles were highly integrated within military enterprises because they could perform a wider variety of missions at lower cost. According to the negotiation record, this specific technology feature led American and Soviet officials to worry that inspections would be used to spy on other weapons capabilities and plants.[47] The treaty called for an elimination of these missiles, which was verified with inspections, but after a set period, states would rely on their intelligence capabilities rather than inspection of military areas. Phasing out inspections helped to dampen the security risks associated with long-term observation of military units and installations.

States have also reached several agreements designed to inhibit the spread of ballistic missiles. In 1987, the Missile Technology Control Regime (MTCR) established an informal, non-treaty based security institution for member governments to control the export of specific missile technology and components. The MTCR has no formal mechanism to enforce or verify compliance. In 2002, the Hague Code of Conduct Against Ballistic Missile Proliferation (HCOC) was designed to supplement the MTCR with normative guidelines for "conduct" in trading and developing ballistic missiles. It also has no inspection system for verifying compliance. The outcomes align with our expectations that states can reach agreements with a wide variety of verification measures—in these cases reliance on unilateral collection methods.

Theory Support: <u>Strong for H1</u>.

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[46] George Bunn, *Arms Control by Committee: Managing Negotiations with the Russians* (Stanford: Stanford University Press, 1992), 106–8.

[47] Steven Pifer et al., "The Treaty on Intermediate-Range Nuclear Forces: History and Lessons Learned" (Washington: Brookings Institution Press, 2012).

Space

Technology Definition

Space technology refers to objects that are placed beyond the earth's atmosphere, including satellites and spacecraft. We treat launch technology—the rockets that carry payloads to space—separately (see Rockets). Most modern spacecraft also fall into the Hypersonic Vehicle category because they operate in the hypersonic regime with some degree of maneuverability upon reentry into the earth's atmosphere. We exclude the hypersonic features here to focus on characteristics unique to spacecraft in orbital planes. In its early phases, innovation in space was dominated by competition between the United States and the Soviet Union.[1] But more states gradually developed space capabilities, with a sharp increase since 2010. Today, more than 70 counties have space assets, such as small commercial satellites.[2]

Space provides for numerous dual use applications. On the military side, satellites support communications, targeting, command-and-control, and reconnaissance. In-space assets can also be weapons themselves, though such systems have not been deployed by states. For example, a "directed energy" or space-based laser capability could be used to destroy other satellites as a space-based anti-satellite weapon (ASAT) or to intercept and destroy missiles taking off from the earth's surface as part of a missile defense system. On the civilian side, space exploration is an ongoing scientific activity, and satellites are used for communications, research, and collection of commercial geographic data. That this technology is dual use was recognized from the start of the space age.[3]

Time Period Boundaries

We consider two time periods: 1957–1970 and 1970–2020. As part of its involvement in the International Geophysical Year (IGY), the United States announced its intent to begin work on an orbiting satellite program in 1955. In the same year, the Soviet Union also announced their intentions to launch a satellite in the IGY. Sputnik 1 was successfully launched by the Soviet Union in October 1957, followed closely by the American Explorer 1 launched a few months later in January 1958. Prior to the 1970, satellite capabilities were largely the purview of government agencies, both military and

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[1] For a comprehensive history of the early space age, see Walter A. McDougall, *The Heavens and the Earth: A Political History of the Space Age* (New York: Basic Books, 1985).
[2] For a more detailed assessment, see Bryan R. Early, "Exploring the Final Frontier: An Empirical Analysis of Global Civil Space Proliferation," *International Studies Quarterly* 58, no. 1 (March 1, 2014): 55–67.
[3] See, for example, Project RAND, *Preliminary Design of an Experimental World-Circling Spaceship* (Douglas Aircraft Company, Santa Monica Plant Engineering Division: 1946), https://www.rand.org/pubs/special_memoranda/SM11827.html. For an overview, see McDougall, *The Heavens and the Earth*, 97–111.

civilian. From the 1970s onward, satellite capabilities and their applications in commercial or joint government and commercial partnerships steadily increased. Lifespans of observation satellites have also increased, as have the numbers of yearly launches. Observation satellite missions became less likely to fail, and the operational life span tripled from about 3 years in the 1970s to over 8 years in 2015.[4] These factors led to a major shift in both distinguishability and integration after 1970.

Space, 1957–1970

Distinguishability: High

Unlike the rocket technology used for launching objects into space, early space-based capabilities were themselves distinguishable for four reasons. First, although the physical characteristics of civilian and military space capabilities were similar, these early systems often emitted signatures that revealed intended use. In 1969, for example, an American intelligence analyst used open-source information about the orbital parameters and onboard capabilities (e.g., instrumentation or radio telemetry features) of Soviet satellites to differentiate peaceful scientific platforms from their military counterparts. "It is a fact," the study concluded, "that anyone who is interested, and who knows the hall-signs, can much more often than not identify the type of any space vehicles the Soviets have launched without benefit of additional information."[5] The rudimentary nature of the technology enabled such distinctions to be made with relative ease at the time.

Second, despite leveraging the same core technologies, military and civilian space capabilities followed divergent development pathways to achieve different goals. During this period, space-based technology was the exclusive purview of government actors with distinct goals within each realm. On the military side, satellites were designed to perform reconnaissance, early warning, navigation, and communication missions.[6] There was also some consideration of using satellites and spacecraft for orbital bombardment of targets on earth.[7] Military and intelligence requirements drove design features on all these systems as part of a highly secretive development

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[4] Alan Belward and Jon Skøien, "Who Launched What, When and Why; Trends in Global Land-Cover Observation Capacity from Civilian Earth Observation Satellites," *ISPRS Journal of Photogrammetry and Remote Sensing* (May 2015), 115–128, www.sciencedirect.com/science/article/pii/S0924271614000720, 10.1016/j.isprsjprs.2014.03.009.
[5] Edward M. Hinman, "The Interpretation of Soviet Press Announcements of 'Cosmos' Satellite Launchings," *Studies in Intelligence*, Vol. 13, No. 3 (Summer 1969), 22, https://nsarchive2.gwu.edu//NSAEBB/NSAEBB501/docs/EBB-17.pdf.
[6] For overviews, see James Clay Moltz, *The Politics of Space Security: Strategic Restraint and the Pursuit of National Interests* (Stanford, CA: Stanford Security Studies, 2008), 69–123; Paul Stares, *Space and National Security* (Washington, DC: Brookings Institution Press, 1987).
[7] On consideration of Fractional Orbital Bombardment Systems (FOBS), see Sean N. Kalic, *US Presidents and the Militarization of Space, 1946-1967* (College Station: Texas A&M University Press, 2012), 60–88.

process.[8] On the civilian side, satellites and spacecraft were developed to advance scientific exploration. Some activities, such as manned-space flight or preparations for lunar landings, were largely driven by the allure of national prestige rather than hard economic or security factors.[9] These capabilities were therefore designed to accomplish clear peaceful goals, often out in the open to herald major breakthroughs.

The initial development of American and Soviet spy satellites illustrates some of these design differences. The first Soviet spy satellite, called the Zenit, built on the same capsule used for peaceful purposes to carry animals and later humans into orbit. But the cameras to be placed in the Zenit required a far more complex and sophisticated stabilization system than the civilian capsule, which resulted in a major redesign effort.[10] Similarly, the first American spy satellite, named CORONA, also converted the same technology from the Gemini-Agena Target Vehicle used by NASA during its peaceful Gemini space exploration program. But the panoramic camera design for CORONA required the satellite to be precisely stabilized around all three axes. Since Gemini-Agena was not developed with such an active control system, the spacecraft had to be redesigned to meet the CORONA mission requirements.[11]

Third, the deployment patterns for military satellites tended to deviate from most peaceful and scientific activities in space. At this early stage of technological development, many spy satellites had to be placed in a retrograde polar orbit that passed over the North and South Poles. This came to be known as the 'reconnaissance orbit,' one study noted, because the "rotating Earth turns beneath this fixed orbital plane, presenting a new swath of territory on each pass."[12] The polar orbit was therefore optimal for first generation American and Soviet military satellites with limited maneuverability and collection sensors. The placement of satellites in 'reconnaissance orbit' tended to reveal intended use, although some peaceful satellites also collected data along the same flight path. In the United States, military satellites had to be launched into polar orbit from Vandenberg in California for safety reasons; whereas the NASA facility at Cape Kennedy handled many of the more visible launches of peaceful and scientific payloads into other orbits.[13]

The United States and Soviet Union also considered deploying military assets and even weapons (e.g., nuclear weapons or Fractional Orbital Bombardment Systems) to space and lunar surface. In the United States, these ambitions were restrained in part when the lunar landing mission was assigned to NASA, a civilian agency. This meant that the majority of US space exploration was done openly rather than covertly, which

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[8] See Philip Taubman, *Secret Empire: Eisenhower, the CIA, and the Hidden Story of America's Space Espionage* (London, UK: Simon & Schuster, 2004).
[9] See Teasel Muir-Harmony, *Operation Moonglow: A Political History of Project Apollo* (New York, NY: Basic Books, 2020); Paul Musgrave and Daniel H. 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 (ed 2018): 591–626, https://doi.org/10.1017/S0020818318000139.
[10] Pat Norris, *Spies in the Sky: Surveillance Satellites in War and Peace* (New York, NY: Praxis, 2007), 68.
[11] Albert D. Wheelon, "CORONA: A Triumph of American Technology," in *Eye in the Sky: The Story of the Corona Spy Satellites*, ed. Dwayne A. Day, Logsdon, John M., and Brian latell (Washington, DC: Smithsonian Books, 1999), 35–36.
[12] Wheelon, 34.
[13] Norris, *Spies in the Sky*, 74.

made it observable to the Soviet Union and thus distinguishable from military programs.[14]

Fourth, the conversion speed from civilian to military capabilities was quite slow during this period because most space-based platforms had limited functions and optionality. For example, an early satellite deployed on a fixed orbit with equipment for collecting meteorological data could not be readily converted into an intelligence asset at the time, let alone a weapon. However, the United States and Soviet Union began working on more maneuverable satellite programs that set the stage for concerns about quicker conversion to weapons or other military assets in the late-1960s, as orbital propulsion capabilities promised to turn even a benign satellite into an anti-satellite system.[15]

The distinguishable nature of space-based capabilities comes across in many of the intelligence products from this era. Both civilian and military space capabilities were closely held as state secrets by the United States and the Soviet Union. The US intelligence community devoted considerable resources to tracking Soviet space developments. Analysis of declassified US intelligence products suggests that the United States was quite successful in identifying the purposes of Soviet satellites, even when the Russians tried to conceal them.[16] National Intelligence Estimates produced during this period identify scientific developments and delineate capabilities seen as having a military purpose.[17] In estimating Soviet capabilities, the NIEs included a separate military section. There is little indication of concern in the NIEs (from 1962 and 1965 for example) that US intelligence would have a hard time differentiating between scientific satellites and those with more advanced "weapons" purposes if the USSR chose to purse weapons in space. A 1965 NIE noted that US intelligence would have difficulty identifying the start of Soviet military space programs but other documents indicate that the deployed weapons in space could be detected.[18] Early spaced tracking capabilities further allowed for distinguishing between military and civilian space objects.[19]

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[14] For an overview of declassified documents that shed light on consideration of covert lunar missions, see Jeffrey T. Richelson, "Soldiers, Spies and the Moon: Secret U.S. and Soviet Plans from the 1950s and 1960s," National Security Archive, Electronic Briefing Book No. 479, July 20, 2014, https://nsarchive2.gwu.edu/NSAEBB/NSAEBB479/.

[15] On these fears, see Director of Central Intelligence, "The Soviet Space Program," National Intelligence Estimate No. 11-1-69, Central Intelligence Agency, June 19, 1969, DNSA, 9, https://nsarchive2.gwu.edu//NSAEBB/NSAEBB501/docs/EBB-16a.pdf.

[16] See Hinman, "The Interpretation of Soviet Press Announcements of 'Cosmos' Satellite Launchings."

[17] For an excellent overview, see Jeffrey T. Richelson, "U.S. Intelligence and the Soviet Space Program," National Security Archive, Electronic Briefing Book No. 501, February 4, 2015, https://nsarchive2.gwu.edu//NSAEBB/NSAEBB501/.

[18] Director of Central Intelligence, "The Soviet Space Program," National Intelligence Estimate No. 11-1-62, Central Intelligence Agency, December 5, 1962, DNSA, https://nsarchive2.gwu.edu//NSAEBB/NSAEBB501/docs/EBB-05.pdf; Director of Central Intelligence, "The Soviet Space Program," National Intelligence Estimate No. 11-1-65, Central Intelligence Agency, January 27, 1965, DNSA, https://nsarchive2.gwu.edu//NSAEBB/NSAEBB501/docs/EBB-11.pdf.

[19] For example, NORAD was charged with tracking space objects and maintains a Satellite Catalog to the present day. The first objects catalogued (NORAD CAT ID 1 and 2) are the rocket body and payload associated with Sputnik I in 1957.

Finally, it should be noted that there were some areas within the space-based context where distinguishability was lower. For example, early manned reentry vehicles, drew heavily from ballistic missile reentry vehicle designs, which were much more indistinguishable at the time (see Rockets and Hypersonic Vehicles).

Integration: Low (Military) / Low (Civilian)

Satellites and spacecraft exhibited low integration at the dawn of the space age for several reasons. First, the rudimentary nature of the technology limited the range and variety of uses within both the military and civilian spheres. The CORONA and Zenit satellites revolutionized intelligence, to be sure. These platforms played a significant role in reducing uncertainty about strategic nuclear forces during the Cold War. But within the military realm, satellites only performed a limited range of high value tasks during this period, notably reconnaissance, early warning, and communication related to nuclear forces. In the United States, for example, CORONA satellites were often focused on surveilling Soviet strategic nuclear capabilities.[20] Military reliance on satellites grew quickly to perform these critical tasks, but the capabilities were employed separately from tactical operations and were focused on strategic missions. Actual space-based weapon systems were considered but never deployed at the time.

On the civilian side, the technology was even more limited to niche scientific missions and space exploration. Moreover, space-based capabilities were not integrated with other innovations or capabilities on either the civilian or military side. Development in both spheres was considered highly sensitive in the context of the US-USSR competition. Military and civilian activities started to diverge somewhat with the founding of NASA, but they remained relatively isolated from other capabilities.[21] Early commercial activities in space were placed under significant governmental oversight which further contributed to the isolation of these industries.[22] Second, the massive cost of developing and operating space-based technology contributed to its isolation. The total cost of the CORONA program amounted to $850 million (1960 US dollars).[23] On the civilian side, the human spaceflight programs of the United States consumed considerable financial resources: $277 million (1965 US dollars) for Project Mercury; $1.3 billion (1967 US dollars) for Gemini; and $25.4 billion (1973 US dollars) for Project Apollo.[24] This balance sheet meant that military satellites and civilian space programs were extremely expensive niche assets.

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[20] For a good overview of how the military utility of satellites evolved over time, see Stares, *Space and National Security*, 8–72.

[21] See McDougall, *The Heavens and the Earth*, 157–76.

[22] See, for example, the Communications Satellite Act of 1962, available at https://www.govinfo.gov/content/pkg/STATUTE-76/pdf/STATUTE-76-Pg419.pdf.

[23] Dwayne A. Day, Logsdon, John M., and Brian Iatell, eds., *Eye in the Sky: The Story of the Corona Spy Satellites* (Washington, DC: Smithsonian Books, 1999), 182.

[24] Claude Lafleur, “Costs of US Piloted Programs,” The Space Review, March 8, 2010, https://www.thespacereview.com/article/1579/1.

Outcomes

<u>Agreement with unilateral collection methods.</u> In 1967, the United States and Soviet Union signed the Outer Space Treaty (OST), which banned the placement of nuclear weapons or other weapons of mass destruction in orbit. It also banned the militarization of celestial bodies, limiting use of the Moon for only peaceful purposes.[25] The Outer Space Treaty does not ban militarization of space in general, but does ban both a full class of weapons and any military activities, such as testing or establishing bases, that would be done on a celestial body. The treaty effectively legitimizes the use of space for intelligence collection and allows for the future possibly of military use.[26]

The Outer Space Treaty does not include any provisions for monitoring or verification. After internal debate, US officials were convinced that national intelligence capabilities would be sufficient to detect violations both at the time and in the future. The administration publicly announced it possessed the capabilities to verify compliance with the OST, despite some objections by the Chairman of the Joint Chiefs of Staff (CJCS) and others. There were some mixed views about detection of space objects more broadly, but more consensus on identifying nuclear weapons, particularly large-scale deployments in space that would be militarily significant.[27]

In preparing its position on the Outer Space Treaty, the United States did consider monitoring and inspection of launches to confirm that no nuclear weapons would be present.[28] Monitoring was assessed as unnecessary. The United States was eager to avoid any restrictions on its military reconnaissance satellites, and there was some concern that pushing for inspection of some launches would give the Soviets leverage to push for monitoring American reconnaissance launches as well. It was also seen as unlikely that either side had strong incentives to secretly cheat on the agreement. Ballistic missiles provided a more effective and economical way to deliver nuclear warheads. The benefit of a nuclear threat from space would be largely psychological rather than technical, and in that sense also unlikely to be secret if it were ever pursued.[29]

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[25] Christopher D. Johnson, "Current status of international space law and its applicability to future arms control agreements," Presentation, Future Arms Control in an Era of Strategic Competition, December 18, 2020, http://bit.ly/SpaceLawDec2020.

[26] McDougall, *The Heavens and the Earth*, 274–75.

[27] While confidence was expressed in the United States' ability to detect all satellites, including a 'bomb-in-orbit' at low orbits, the capabilities had limits and countermeasures could make detection impossible. Ultimately, the administration took the position that anything short of large numbers of weapons in orbit would be unlikely to upset the strategic balance. See Taunton Paine, "Bombs in Orbit? Verification and Violation under the Outer Space Treaty," The Space Review, March 19, 2018, https://www.thespacereview.com/article/3454/1.

[28] See "Draft Recommendations Respecting U.S. Approach to a Separate Arms Control Measure for Outer Space." General CIA Records, n.d. Document Number (FOIA) /ESDN (CREST): CIA-RDP66R00638R000100140010-7, https://www.cia.gov/readingroom/document/cia-rdp66r00638r000100140010-7.

[29] "Draft Recommendations Respecting U.S. Approach to a Separate Arms Control Measure for Outer Space," 11.

The United States therefore sought to rely on its own national detection capabilities to monitor the Outer Space Treaty. As expected, the Soviet Union was overall more reluctant to accept any intrusive monitoring. Testifying on the OST before Congress, Chairman of the Joint Chiefs of Staff (CJCS) General Earle G. Wheeler reemphasized several times that, despite potential verification difficulties, the United States would prefer to rely upon its own NTM to address the verification issue rather than attempting to create an international on-site inspection regime for objects in space. The JCS therefore specifically called for "intensified U.S. efforts to develop capabilities to detect and verify the orbiting of nuclear weapons or those threatening mass destruction" as well as a general "increase in our military efforts in space not prohibited by the treaty."[30]

Several other agreements address space-based capabilities in addition to other limitations. The Limited Test Ban Treaty (1963) banned nuclear testing in outer space, and ABM Treaty (1972) banned systems which include space-based capabilities intended to take down or interfere with ballistic missiles. In these cases, the United States would have preferred treaty-mandated ways to observe Soviet behavior, but it was also sufficiently sure of its ability to detect violations, including testing and the placement of nuclear weapons in space, to be able to accept a treaty without additional monitoring measures.

Theory Support: <u>Strong for H1</u>.

Space, 1970–2020

Distinguishability: <u>Low</u>

Advances in space technology during the 1970s degraded all four distinguishability attributes. First, the physical characteristics of many new civilian capabilities were often identical to military platforms and even potential weapons.[31] The main problem here was that satellites and spacecraft became far more capable during the 1970s and 1980s, which meant that ostensibly civilian capabilities could perform military missions in space.[32] This overlap was reflected in a US National Intelligence Estimate from 1983,

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[30] Peter L. Hays, "United States Military Space: Into the Twenty-First Century," INSS Occasional Paper (USAF Academy, Colorado and Maxwell AFB, Alabama: USAF Institute for National Security Studies and Air University Press, 2002), 70, https://apps.dtic.mil/dtic/tr/fulltext/u2/a435077.pdf; *Treaty on Outer Space. Hearings, Ninetieth Congress, First Session, on Executive D, 90th Congress, First Session.* (Washington, 1967), 84–85, http://hdl.handle.net/2027/uc1.$b643624.

[31] Johnson-Freese, *Space as a Strategic Asset*; Todd Harrison et al., "Escalation and Deterrence in the Second Space Age" (Washington, DC: Center For Strategic and International Studies, October 2017), https://www.csis.org/analysis/escalation-and-deterrence-second-space-age.

[32] Paul Stares, "Space and US National Security," *Journal of Strategic Studies* 6, no. 4 (December 1983): 31–48, https://doi.org/10.1080/01402398308437166; Ashton B. Carter, "Satellites and Anti-Satellites: The Limits of the Possible," *International Security* 10, no. 4 (1986): 46–98, https://doi.org/10.2307/2538950.

which noted that the category of Soviet satellites with both military and civil functions was growing in tandem with the expansion of Soviet space capabilities.[33] In the United States, some satellites, such as the constellation comprising the Global Positioning System (GPS), started to support both military and civilian users at the same time.[34]

Even more worrisome, advances in civilian spacecraft and orbital space station technology made them harder to distinguish from potential weapons. After the Apollo era ended, the focus of manned spaceflight turned increasingly toward sustained missions aboard space stations, such as Salyut 1-7 (1971-1986), Skylab (1973-1979), Mir (1986-2001), and the Space Shuttle (1981-2011).[35] Since these civilian platforms could perform a wider variety of maneuverable rendezvous operations in space, it became difficult to assuage concerns about military applications. During the Cold War, for instance, some Soviet analysts feared that the US Space Shuttle might be used to drop a nuclear weapon on Moscow or attack Soviet satellites in orbit.[36] In a 1984 report to Congress on antisatellite weapons, the Reagan administration noted that, "any nation routinely conducting space rendezvous and docking operations, as the USSR does, could, under the guise of that activity, develop spacecraft equipped to maneuver into the path of, or detonate next to, another nation's spacecraft."[37]

Today, similar concerns apply to capabilities which are relevant for refueling and repair or space debris removal but also for anti-satellite weapons. Both commercial and military actors have shown increased interest in new capabilities such as maneuverable rendezvous and proximity operations (RPO) and space situational awareness (SSA) for satellite inspection, refueling and repair, space debris removal. The United Kingdom's RemoveDEBRIS technology demonstrator, for example, recently tested several capabilities in 2018 to capture and deorbit space debris, including a small harpoon, a net, and large drag-inducing sail.[38] Unfortunately, these seemingly benign features also have applications as co-orbital antisatellite weapons. Russia, China, and the United

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[33] Director of Central Intelligence, "The Soviet Space Program," National Intelligence Estimate No. 11-1-83, Central Intelligence Agency, July 19, 1983, CIA Reading Room, 10, https://www.cia.gov/readingroom/document/cia-rdp00b00369r000100050007-1.

[34] Irving Lachow, "The GPS Dilemma: Balancing Military Risks and Economic Benefits," *International Security* 20, no. 1 (1995): 126, https://doi.org/10.2307/2539220. Beyond GPS, see Adam J. Ochs, "Use of Commercial Imagery Capabilities in Support of Maritime Domain Awareness," M.S. Thesis (Monterey, CA: Naval Postgraduate School, 2015), https://apps.dtic.mil/sti/pdfs/ADA632504.pdf.

[35] Burrows, *This New Ocean*.

[36] Bart Hendrickx and Dwayne A. Day, "Target Moscow: Soviet Suspicions about the Military Uses of the American Space Shuttle (Part 1)," The Space Review, January 27, 2020, https://www.thespacereview.com/article/3873/1.

[37] Ronald Reagan, Report to Congress: US Policy on ASAT Arms Control (Washington, DC: Government Printing Office, 1984).

[38] See Jason L. Forshaw et al., "RemoveDEBRIS: An in-Orbit Active Debris Removal Demonstration Mission," *Acta Astronautica* 127 (October 2016): 448–63, https://doi.org/10.1016/j.actaastro.2016.06.018; Jason L. Forshaw et al., "Final Payload Test Results for the RemoveDebris Active Debris Removal Mission," *Acta Astronautica* 138 (September 2017): 326–42, https://doi.org/10.1016/j.actaastro.2017.06.003; "Falcon 9 Launched a Space Junk Sweeper Into Orbit," Time, accessed March 8, 2021, https://time.com/5225670/spacex-space-junk-cleaner-launch/.

States all conducted numerous RPO and SSA tests from the early 2000s and 2010s, and the civilian versus military uses were particularly difficult to distinguish.[39]

Second, the development pathways for many military platforms started to converge with civilian and especially commercial space capabilities over time. Government work on dedicated anti-satellite weapons remained largely separate from the civilian research and development sphere, to be sure.[40] But the commercial development of space started to dovetail with military applications, especially as public-private partnerships began to grow during the 1980s.[41] In 1983, for example, US officials recommended that the Reagan administration transfer remote sensing technology under US government control to private entities in order to offset the economic costs while maintaining a "leadership position" in developing next generation systems.[42] The evolution of the Global Positioning System (GPS) provides another apt illustration, as the satellite constellation was first prototyped by the Department of Defense in 1978, but then commercial actors helped mature the technology in the decades ahead.[43] This trend accelerated in the late-1990s and early-2000s with the initial boom in commercial satellite systems for imaging, including IKONOS (1999), GeoEye (2008), WorldView (2007).[44]

Third, the deployment patterns for civilian and military assets in space became harder to differentiate for several reasons. The most obvious problem was that the growing number of total satellites and spacecraft in orbit made it more difficult to track uses with confidence. In addition, spacecraft and satellites increasingly came to perform multiple functions once deployed in orbit. In 1982, for example, a CIA assessment on the rapidly expanding Soviet space program concluded that Moscow would reap "important military and economic payoffs" from the ostensibly peaceful Mir space station.[45] Although the CIA noted it could still discern some "purely civilian projects like the multispectral photography provided by Earth resources satellite missions," the new space station would provide the Soviet military with civilian cover "to pursue research in

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[39] Brian Weeden, “Through a Glass, Darkly: Chinese, American, and Russian Anti-Satellite Testing in Space,” The Space Review, March 17, 2014, https://www.thespacereview.com/article/2473/1; Brian Weeden, “The Space Review: Dancing in the Dark: The Orbital Rendezvous of SJ-12 and SJ-06F,” The Space Review, August 30, 2010, https://www.thespacereview.com/article/1689/1; Bruce W. MacDonald, “China, Space Weapons, and U.S. Security,” Council on Foreign Relations, September 2008, https://www.cfr.org/report/china-space-weapons-and-us-security.

[40] Carter, “Satellites and Anti-Satellites”; Johnson-Freese, *Space as a Strategic Asset*; Stares, “Space and US National Security.”

[41] From 1982 to 1988, several US policy documents and legislation directed the government to expand private sector activities and development in space, license and regular commercial launch activities, and ultimately purchase launch services from the private sector.

[42] Malcolm Baldrige, Cabinet Council on Commerce and Trade, "Transfer of Civil Space Remote Sensing Systems to the Private Sector," Decision Memorandum, February 4, 1983, CIA Reading Room, https://www.cia.gov/readingroom/document/cia-rdp85m00364r001903640005-7.

[43] Lachow, “The GPS Dilemma.”

[44] The INTELSAT Agreement (1971) set the foundation by establishing the international telecommunications satellite organization, INTELSAT, to coordinate globally available satellite communications among US allies and partners.

[45] Central Intelligence Agency, "Outlook for Rapid Expansion of Soviet Space Programs Through 1986," Intelligence Assessment, Directorate of Intelligence, SOV 82-10155, October 1982, CIA Reading Room, 12, https://www.cia.gov/readingroom/document/cia-rdp83t00853r000200020002-1.

ASW, ASAT, early warning, and other important defensive and offensive missions."[46] The Soviets also worried that the United States would leverage its civil space exploration for military purposes. This concern continued to fester in the decades ahead. As a report from the Congressional Research Service found in 2004, "Both [military and civilian] sectors use communications, navigation, weather, and remote sensing/reconnaissance satellites, which may operate at different frequencies or have different capabilities, but have similar technology ... DOD uses some civilian satellites and vice versa."[47] The report concluded that the military or peaceful functions performed by deployed satellites were "not easily divided."[48] The more recent adoption of hosted payloads and ride shares of national security payloads on commercial and civil satellites and launch services further blurred this division.[49]

Fourth, the conversion speed from civilian to military capabilities accelerated as space capabilities gained greater functionality. By the 2010s, many commercial satellites could supply users with remote sensing and imagery, breaking the government monopoly on advanced overhead analysis.[50] In 2022, Starlink micro-satellites and terminals from SpaceX provided critical communications support (broadband data) to the Ukrainian government and military.[51] Beyond support services, commercial platforms developed for maneuverable rendezvous and proximity operations (RPO) and space situational awareness (SSA) could be rapidly turned into co-orbital ASAT weapons, as noted above.

Integration: <u>High</u> (Military) / <u>High</u> (Civilian)

Space technology became highly integrated within both the military and civilian realms after 1970. The range and variety of uses for satellites and spacecraft underwent a dramatic expansion. On the military side, the United States and Soviet Union pioneered the use of space capabilities to support conventional military forces, especially amid advances in information technology during the 1980s. The Americans harnessed their space systems to support breakthroughs in precision weapons and intelligence,

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[46] Ibid.
[47] Marcia S. Smith, "U.S. Space Programs: Civilian, Military, and Commercial," Congressional Research Service Report, September 2004.
[48] Ibid.
[49] Peter A. Cunningham, "Military Payloads Hosted on Commercial Satellites: How Can the Space and Missile Systems Center Increase the Number of Commercially Hosted Military Payload Contract Awards?," Wright Flyer Paper No. 53 (Maxwell AFB, AL: Air University Press, Air Force Research Institute, December 2015); National Reconnaissance Office, "NRO Launches Second Dedicated Mission with SpaceX," Press Release #09-20, December 19, 2020; National Reconnaissance Office, "NRO Launches Two IMPACT Small Satellites as Rideshare on NG-12," National Reconnaissance Office, November 2, 2019.
[50] See Erik Lin-Greenberg and Theo Milonopoulos, "Private Eyes in the Sky: Emerging Technology and the Political Consequences of Eroding Government Secrecy," *Journal of Conflict Resolution* 65, no. 6 (July 1, 2021): 1067–97, https://doi.org/10.1177/0022002720987285.
[51] Vivek Wadhwa and Alex Salkever, "How Elon Musk's Starlink Got Battle-Tested in Ukraine," *Foreign Policy* (blog), May 4, 2022, https://foreignpolicy.com/2022/05/04/starlink-ukraine-elon-musk-satellite-internet-broadband-drones/.

surveillance, and reconnaissance (ISR).[52] The Soviets also made major investments in space capabilities to enhance the lethality of their conventional forces. "As their capabilities in space increase," a CIA assessment noted in 1982, "the Soviets also will become increasingly dependent upon the new systems for intelligence collection, navigation support, and maintaining order-of-battle and targeting data."[53] The applications for satellites and spacecraft expanded far beyond niche applications in the strategic nuclear realm, which led the superpowers to become more interested in holding these assets at risk. In the mid-1970s, the Soviets began to test ground-based and co-orbital antisatellite (ASAT) systems; the United States started to successfully test ASAT weapons in 1985 as well.[54] After the Cold War, many other nations joined the superpowers in using space capabilities to enhance military effectiveness. By 2000, over 37 states had acquired satellite capabilities.[55] In 2019, analysts concluded that space systems were "arguably fundamental to the conduct of advanced conventional warfare for all advanced powers. This integration has opened new windows of opportunity and vulnerability for the United States and its allies and potential adversaries alike."[56]

On the civilian side, space capabilities also underwent a similar expansion in the range and variety of uses. During the 1980s, commercial applications of satellite services grew a rapid clip to include scientific exploration, shipping and logistics, environmental management, and other activities across many sectors of the economy.[57] In one notable example, two commercial satellites were used in 1986 to produce public photographs of the damaged nuclear reactor at Chernobyl.[58] "An ever-greater volume of civil and commercial activities had come to rely on support from communication and meteorological satellites" by the end of the Cold War, Forrest Morgan notes, "and new markets were emerging in such areas as space-based spectral imaging for resource management and geodesic survey."[59] In the 1990s, commercial launches and payloads continued to place growing numbers of civilian satellites into orbit, eventually disrupting

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[52] Forrest E. Morgan, “Deterrence and First-Strike Stability in Space: A Preliminary Assessment” (RAND Corporation, April 2, 2010), https://www.rand.org/pubs/monographs/MG916.html; Schneider, “The Capability/Vulnerability Paradox and Military Revolutions,” September 19, 2019.
[53] Central Intelligence Agency, "Outlook for Rapid Expansion of Soviet Space Programs,” 13.
[54] Kaila Pfrang and Brian Weeden, “Russia Co-Orbital Anti-Satellite Testing,” Secure World Foundation, August 2020, https://swfound.org/media/207051/swf_russian_co-orbital-asat_aug2020.pdf; Morgan, “Deterrence and First-Strike Stability in Space,” 11–12.
[55] Bryan R. Early, “Exploring the Final Frontier: An Empirical Analysis of Global Civil Space Proliferation1,” *International Studies Quarterly* 58, no. 1 (March 1, 2014): 55–67, https://doi.org/10.1111/isqu.12102.
[56] Benjamin W. Bahney, Jonathan Pearl, and Michael Markey, “Antisatellite Weapons and the Growing Instability of Deterrence,” in *Cross-Domain Deterrence: Strategy in an Era of Complexity*, ed. Jon R. Lindsay and Erik Gartzke (New York, NY: Oxford University Press, 2019), 129. See also James M. Acton, “Escalation through Entanglement: How the Vulnerability of Command-and-Control Systems Raises the Risks of an Inadvertent Nuclear War,” *International Security* 43, no. 1 (August 2018): 56–99, https://doi.org/10.1162/isec_a_00320.
[57] Moltz, *Crowded Orbits*.
[58] Nell Henderson, “Civilian Satellites Penetrate Soviet Secrecy, Photograph Plant,” *Washington Post*, May 2, 1986, https://www.washingtonpost.com/archive/politics/1986/05/02/civilian-satellites-penetrate-soviet-secrecy-photograph-plant/8a2de19f-c539-4a4b-a5ec-45638fde660a/.
[59] Morgan, “Deterrence and First-Strike Stability in Space,” 12.

the traditionally state-operated market for overhead analysis.[60] The subsequent boom in commercial satellite systems for imaging was soon followed by an expansion in small satellites, which went from 40–60 launches per year from 2000–2012, to hundreds in a month in 2020.[61]

The cost of developing and fielding space systems remained high in absolute terms, especially for bespoke satellites or advanced spacecraft. However, the rise of commercial services and capabilities lowered the relative financial intensity associated with accessing and even possessing satellites.[62] This played a major role in making orbital infrastructure essential to military and civilian activities in many nations today.

Outcomes

Consideration but no agreements. Since the mid-1970s, there have been no limits on military competition in space.[63] Strategic arms treaties (SALT, START) included a vague provision to "not to interfere with the national technical means of verification of the other Party," which is not further defined but often interpreted to mean a ban on attacking reconnaissance satellites, including by using space weapons, but does not limit the possession of such capabilities. Attempts at negotiations over antisatellite weapons floundered in both 1978–79 and again in 1987–89. In both cases, American and Soviet negotiators explicitly recognized that the dual use indistinguishability of space-based technology presented a formidable obstacle to cooperation. In the Carter administration, a key element that precluded agreement was concern about systems with "residual ASAT capabilities" of other space-based systems, or in other words, that space-based systems with other primary purposes could also be used as weapons. The Soviets specifically suggested that the forthcoming US Space Shuttle, a clearly civilian capability from the American point of view, should be included as an ASAT system. The United States in turn had concerns about covert Soviet capabilities.[64] These

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[60] Harrison et al., "Escalation and Deterrence in the Second Space Age," 6.
[61] See "UCS Satellite Database," Union of Concerned Scientists, Updated January 1, 2022, https://www.ucsusa.org/resources/satellite-database. One notable commercial player is SpaceX, which has sent 1,385 Starlink small communications satellites into orbit since 2018, see Stephen Clark, "SpaceX Launches 25th Mission for Starlink Internet Network," *Spaceflight Now* (blog), March 24, 2021, https://spaceflightnow.com/2021/03/24/spacex-launches-25th-mission-to-build-out-starlink-internet-network/.
[62] "The Low-Cost Mini Satellites Bringing Mobile to the World," *BBC News*, February 23, 2018, sec. Business, https://www.bbc.com/news/business-43090226.
[63] A small number of states signed the Agreement Governing the Activities of States on the Moon and Other Celestial Bodies (Moon Agreement) in 1979. This agreement demilitarizes the Moon, banning all weapons, fortifications, military bases on the moon, and weapons of mass destruction in orbit around the moon. However, none of the states with independent space launch capabilities are parties to the agreement, with the exception of India which signed but did not ratify.
[64] Christopher A. Ford, "Arms Control in Outer Space: History and Prospects," Arms Control and International Security Papers (Washington, D.C: Office of the Under Secretary of State for Arms Control and International Security, U.S. Department of State, July 24, 2020); "U.S. Policy on ASAT Arms Control, Communication from the President," Document, April 3, 1984, https://congressional.proquest.com/legisinsight?id=13575%20H.doc.197&type=DOCUMENT&a

disagreements arose in part due to indistinguishability of space-based systems as compared to highly distinguishable and observable systems like ballistic missiles found in SALT and the ABM Treaty.

In the early 1980s, the Soviet Union made a number of proposals for limiting weapons in space, including draft space treaties at the UN on banning any kind of weapon in orbit.[65] The United States rejected these proposals. In 1985, the United States became more serious about engaging with the Soviet Union and space talks was one of the three talks agreed to at the Geneva Summit (the other two being on intermediate range missiles and strategic missiles). When a new round of space talks began in the late 1980s, the Reagan administration argued that restrictions on ASAT capability would also affect maneuverable spacecraft which could be used for both military and civilian purposes.[66] Further, US officials noted that in some cases it would be nearly impossible to determine whether a satellite in orbit contained a weapon, while in other cases, seemingly civilian activities could mask weapons development.[67] However, using more intrusive inspections to monitor compliance would raise security risks, not only on military capabilities, but also on uses of space in the civilian sector. The report states: "Cooperative measures with the objective of enhancing verification of an ASAT arms control agreement might require access to U.S. space systems that were alleged by the Soviets to have ASAT capabilities, and hence could create an unacceptable risk of compromising the protection of that information. Such measures could also have adverse effects on civil uses of space."[68]

Similar issues constrain discussions through the present day. As the United States, Russia, and China enhance their space capabilities, the topic of arms control over space comes up regularly in expert discussions, think tank reports, and UN meetings. But the dismissal of any possible agreement is common by the very experts who suggest it. In addition to the well-trod distinguishability problems and security risks created by high integration of space capabilities in all aspects of national security, the growing commercial competition in space means that states are less willing to risk proprietary information, and less able to regulate activities by foreign actors.

Theory Support: <u>Strong for H2.</u> In line with our expectations for H2, the evolution of space-based technology over time reveals how variation in distinguishability and integration can doom the prospects for arms control. Traditional theories of arms control struggle to explain why the superpowers were unable to reap mutual benefits by banning this dangerous class of weapons. Some scholars account for this failure by bringing in factors on the nature of the US-Soviet relationship, notably the end of

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ccountid=12702; Roger G. Harrison, "Space and Verification" (USAF Academy, CO: Eisenhower Center for Space and Defense Studies, November 9, 2010), 6–7, https://swfound.org/media/37101/space%20and%20verification%20vol%201%20-%20policy%20implications.pdf.

[65] Stares, *Space and National Security*, 148.

[66] Ronald Reagan, Report to Congress, 5.

[67] Ibid., 5–9.

[68] Ibid., 5.

détente in 1979 coupled with renewed fears about maintaining the nuclear stalemate.[69] Yet our results indicate that changes in both dual use dimensions of space technology during the 1970s plagued every ASAT negotiation with an insurmountable verification problem.

[69] Moltz, *The Politics of Space Security*; Green, *The Revolution That Failed*.

Submarines

Technology Definition

A "submarine" is defined as any submersible vessel capable of independent, underwater propulsion that travels while surfaced, submerged, or diving. This definition excludes diving bells, bathyspheres, bathyscaphes, or submersibles that are incapable of independent propulsion without being tethered to a mother ship, such as remotely operated underwater vehicles (ROVs).[1] Although most submarine capabilities fall within the military domain, peaceful counterparts exist for commercial, tourist, and research purposes. For example, deep-submergence vehicles conduct oceanographic research as part of scientific missions.

Time Period Boundaries

Modern submarine technology debuted in 1866 with the development of steam-powered engines and self-propelled torpedoes.[2] The mechanized revolution transformed submarines into a versatile weapons platform with long ranges and deadly stealth capabilities, as improved diesel-electric engines, torpedoes, underwater navigation systems, and hull designs coalesced in the 1910s. We treat submarines as a single temporal case study because the distinguishability and integration variables exhibited little variation over time.

Submarines, 1866–2020

Distinguishability: <u>High</u>

Submarines are highly distinguishable for three reasons. First, military submarines exhibit clear physical characteristics that make them distinct from their civilian counterparts.[3] Military submarines are typically larger and equipped to host a greater

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[1] See "Dr. Edith A. Widder: Video Transcript," *National Oceanic and Atmospheric Administration: Ocean Exploration*, (undated), https://oceanexplorer.noaa.gov/edu/oceanage/04widder/transcript.html; "Observation Platforms: Submersibles," *National Oceanic and Atmospheric Administration: Ocean Exploration*, (undated), https://oceanexplorer.noaa.gov/technology/subs/subs.html.

[2] Fontenoy, *Weapons and Warfare: Submarines*, 8-9; "Submarine History – The New Navy," *GlobalSecurity*, (undated), https://www.globalsecurity.org/military/systems/ship/sub-history4.htm; Lieutenant Commander J.S. Barnes, U.S.N., *Submarine Warfare, Offensive and Defensive Including a Discussion of the Offensive Torpedo System, Its Effects Upon Iron-Clad Ship Systems, and Influence Upon Future Naval Wars,* (New York: D. Van Nostrand Publishers, 1869); Edwyn Gray, *The Devil's Device: The Story of Robert Whitehead, Inventor of the Torpedo*, (London: Seeley, 1975); Roger Branfill-Cook, *Torpedo: The Complete History of the World's Most Revolutionary Naval Weapon*, (Annapolis: Naval Institute Press, 2014).

[3] Karl Lautenschlager, "The Submarine in Naval Warfare, 1901-2000," *International Security*, vol. 11, no. 3 (Winter 1986-1987): 94-140, https://www.jstor.org/stable/2538886.

number of crewmembers for longer durations.[4] In addition, these vessels are equipped with advanced instruments (military-grade active and passive sonar, radar masts, antenna systems, radio-based and satellite-based navigation systems, etc.), propulsion systems (nuclear-powered, diesel-electric, air-independent propulsion, etc.), and weapons systems (torpedoes, cruise missiles, submarine-launched ballistic missiles).[5]

Second, military submarines are designed to enhance stealth, maneuverability, and strike capabilities. In the early-20th century, for example, the introduction of diesel-electric engines with intake/exhaust snorkels and underwater navigation systems enabled submarines to remain submerged while operating over long distances and time periods.[6] By contrast, commercial and research submarines are typically designed to withstand enormous pressures at great depths, meaning their hulls are designed differently than military submarines, which must make compromises to withstand underwater pressures while still maintaining speed and maneuverability.

Third, military and civilian submarines are deployed in fundamentally different ways. Commercial, tourist, and research submarines, while capable of diving to great depths, are very limited in terms of the overall range of their operation, and most still require a mother ship of some kind to accompany the vessel. The Alvin deep-submergence vehicle, for example, can conduct oceanographic research at depths far beyond military attack and missile submarines, but must be launched from a support vessel.[7] By contrast, military submarines can operate out of ports over extremely long ranges during extended undersea voyages.

Integration: <u>High</u> (Military) / <u>Low</u> (Civilian)

Submarines are highly integrated within the military realm because they perform a wide range of missions, including coastal defense, naval attrition, commerce warfare (commerce raiding), projection of power ashore (e.g. sea-to-land cruise missiles), fleet engagement, long-range reconnaissance and scouting, strategic counterforce and assured destruction (first-strike and second-strike nuclear capabilities), and front line roles in potentially decisive naval battles.[8] Civilian applications for submarines are relatively niche, with only sparing deployment of true submarines (rather than

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[4] One notable exception are so-called midget submarines.
[5] Paul E. Fontenoy, Weapons and Warfare: Submarines, An Illustrated History of Their Impact, (Santa Barbara: ABC-CLIO, 2007): 1-3.
[6] Norman Friedman, *Submarine Design and Development*, (London: Conway Maritime Press, 1984), http://www.shipsproject.org/A7Project/downloads/1984%20Friedman%20Submarine%20Design%20&%20Development.pdf: 53-56.
[7] W. Bruce Stickrott, "The Deep Submergence Vehicle Alvin: An Advanced Platform for Direct Deep Sea Observation and Research," *The Journal of Ocean Technology*, vol. 12, no. 1 (2017), https://www.whoi.edu/wp-content/uploads/2019/03/JOT_Article_250024.pdf; Donald W. Strasburg, Everet C. Jones, and Robert T. B. Iversen, "Use of a Small Submarine for Biological and Oceanographic Research," *ICES Journal of Marine Science*, vol. 31, no. 3 (January 1968): 410-426, https://doi.org/10.1093/icesjms/31.3.410; Lieutenant Doug Perry, U.S.N., "NR-1 within Visual Sight of the Bottom," *Federation of American Scientists*, (undated), https://man.fas.org/dod-101/sys/ship/docs/nr_1.htm.
[8] Lautenschlager, "The Submarine in Naval Warfare, 1901-2000," 95.

submersibles) for tourist, commercial, and research purposes.[9] This has remained the case throughout history, and most submarine capabilities fall within the military domain.

After the modern submarine emerged in 1866, the mechanized revolution transformed the technology into a versatile weapons platform with long ranges and deadly stealth capabilities. Improved diesel-electric engines, torpedoes, underwater navigation systems, and hull designs became available in the 1910s.[10] The invention of sonar and radar provided submarines with enhanced means of detection and navigation. However, this came at the cost of increased vulnerability to anti-submarine warfare, as surface vessels also had access to these new tools. This vulnerability was mitigated when Nazi Germany's Kriegsmarine began installing snorkels on U-Boats that allowed a periscoping submarine to continue running its diesel engines for almost indefinite periods while still submerged. This increased the range of U-Boats as it began to see widespread implementation in 1943 and 1944.[11] After the war, US, British, and Soviet submarine programs developed air-independent propulsion systems.[12]

In 1954, the US Navy commissioned the world's first nuclear-powered submarine, USS Nautilus, which was launched the following year.[13] Nuclear power further expanded the range and variety of military applications for submarines, enabling them to operate over extreme durations with unlimited range, higher speeds, cleaner living quarters, easier operation, and no requirements for recharging or refueling at sea (which could be done on an annual basis). These advantages became significant when

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[9] Bryan Zhang, "Submersibles for Deep Sea Exploration," *Tufts Electrical and Computer Engineering Design Handbook*, (undated), https://sites.tufts.edu/eeseniordesignhandbook/2015/submersibles-for-deep-sea-exploration/; Alex Czartoryski, "The History of Deep-Sea Exploration," *BoaterExam: Boating Safety and Safe Boating Blog*, June 3, 2011, https://www.boaterexam.com/blog/2011/06/history-of-deep-sea-exploration.aspx; Robyn Woodward Janca, "The Deep Reef and Beyond: An Overview of the Development of Tourist Submarine Industry," *OCEANS Conference*, September 18-21, 1989, https://doi.org/10.1109/OCEANS.1989.586673; Alfred S. McLaren, "Transporting Arctic petroleum: a role for commercial submarines," *Polar Record*, vol. 22, no. 136 (January 1984): 7-23, https://doi.org/10.1017/S0032247400004782; F.C. Varley, "The Cargo Submarines: Its History and Possible Application," (Newport: Naval War College, 1972); Robyn Woodward Janca, "The Deep Reef and Beyond: An Overview of the Development of Tourist Submarine Industry," *OCEANS Conference*, September 18-21, 1989, https://doi.org/10.1109/OCEANS.1989.586673.

[10] Vaclav Smil, *Prime Movers of Globalization: The History and Impact of Diesel Engines and Gas Turbines* (Cambridge: MIT Press, 2010),:71. Frank Uhlig Jr., "The Submarine, 1776-1918," *Naval War College Review*, vol. 57, no. 2 (Spring 2004), https://www.jstor.org/stable/10.2307/26394105: 148-149. For more on submarine design, see Captain E.S. Arentzen, U.S.N. and Philip Mandel, "Naval Architectural Aspects of Submarine Design," *The Society of Naval Architects and Marine Engineers,* 1960, https://www.scribd.com/document/368663833/Arentzen-E-S-naval-Architectural-1960-TRANS, and Captain Harry A. Jackson, U.S.N. (Ret.), "Fundamentals of Submarine Design," *SNAME Transactions*, vol. 100 (1992): 419-448, http://kashti.ir/files/ENBOOKS/Fundamentals%20of%20submarine%20concept%20design.pdf. For more on submarines of this era, see Herbert C. Fyfe, *Submarine Warfare: Past, Present, and Future,* (London: Grant Richards, 1902), https://www.gutenberg.org/files/62908/62908-h/62908-h.htm#Page_157.

[11] Friedman, *Submarine Design and Development*: 53-56; "The Schnorchel," *uboat.net*, (undated), https://uboat.net/technical/schnorchel.htm; K.M. Heggstad, "A Unique Snorkel Design," *Naval Engineers Journal*, (June 1965), https://doi.org/10.1111/j.1559-3584.1965.tb04963.x.

[12] Norman Polmar and Kenneth J. Moore, *Cold War Submarines: The Design and Construction of U.S. and Soviet Submarines,* (Dulles: Potomac Books, 2004): 33-48.

[13] Polmar and Moore, *Cold War Submarines*: 57-60.

the Soviet class V-611 submarine “B-67” launched the world’s first R-11FM ballistic missile.[14] Thereafter, the submarine became a critical piece in nuclear deterrence. Modern designs of submarines have continued to make improvements on ballistic-missile and cruise-missile launch systems, underwater navigation, stealth (noise reduction), nuclear propulsion, diesel-electric propulsion, and air-independent propulsion.

Outcomes

Agreements unilateral collection methods or highly restrictive inspections (managed access limits). From 1899 to 1936, states made numerous attempts to negotiate limits and even total bans on submarine construction and use. Some of these efforts failed. At the First Hague Conference (1899), states voted down a proposal to ban the use of submarines in warfare. Although the Washington Naval Treaty (1922) set limits on ships, the participants failed to come an agreement on submarines. Other efforts achieved limited success. The Treaty of Versailles (1919) specifically prohibited Germany from the “construction or acquisition of any submarine, even for commercial purposes.” As a defeated nation, Germany had little choice but to accept this agreement. Under the guise “research” and via partnerships with foreign navies, however, Germany circumvented the treaty’s restrictions and began preparing for rearmament. The London Naval Treaties (1930; 1936) laid out formal rules for submarine warfare and limited the size and firepower of attack submarines. These agreements lacked cooperative monitoring mechanisms because states could verify compliance with national technical means.

The United Nations Register of Conventional Arms (1991) reporting mechanism for UN member states to detail the transfer or production of conventional arms. The register applies to submarines armed and equipped for military use with a standard displacement of 500 metric tons or above, and those with a standard displacement of less than 500 metric tons, equipped for launching missiles with a range of at least 25 kilometers or torpedoes with similar range. The register is voluntary and has no formal mechanism for enforcement. Similarly, the Wassenaar Agreement (1995) seeks to promote transparency into the sale, trade, and distribution of submarines armed and equipped for military use with a standard displacement of 750 metric tons or above, and those with a standard displacement of less than 750 metric tons equipped for launching missiles with a range of at least 25 km or torpedoes with a similar range. The treaty is voluntary and has no formal mechanism for enforcement.

Submarine-launched ballistic missiles (SLBMs) are limited under the Strategic Arms Reduction Treaty (START I, 1991) and New START (2010), both of which include

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[14] Anatoliy Aleksandrovich Zapolskiy, “Missiles Take Off From the Sea,” *Podvodnoye Korablestroyeniye. Proshloye, Nastoyashcheye, Budushcheye* [Submarine Shipbuilding. Past, Present, Future], issue 2 (1994), (published online by Federation of American Scientists), https://nuke.fas.org/guide/russia/slbm/jpuma010_95001.htm.

inspections to verify compliance, albeit with managed access provisions to protect submarines and submarine bases that house the missile launchers.[15]

Theory Support: <u>Strong for H4</u>. These outcomes all lend strong support for our theory because states either used unilateral means to monitor compliance, or, where inspection tools were used, states crafted highly restrictive protocols to safeguard sensitive information.

[15] See Amy F. Woolf, "The New START Treaty: Central Limits and Key Provisions," Congressional Research Service Report, R41219, February 5, 2018, https://crsreports.congress.gov/product/pdf/R/R41219/54.

Torpedo

Technology Definition

A torpedo is traditionally defined as a self-propelled underwater weapon that delivers an explosive warhead against a target, such as a surface vessel or submarine. Modern torpedoes can be launched above or below the water surface from a variety of different military platforms. Torpedoes played an integral role in naval warfare during the First and Second World Wars, which led to improvements in propulsion, guidance, ordinance, and launch capacity. During the Cold War, torpedo technology remained a critical component of anti-submarine warfare, which drove two major technological innovations: (1) the development of acoustic homing; (2) the improvement of software capabilities and propulsion systems offering increased speed and depth. The advent of unmanned underwater vehicles (UUVs) in 1957 for civilian research purposes leveraged similar design principles from military torpedoes, but soon developed novel hull and propulsion systems to perform distinct tasks beyond just payload delivery (some of these systems may also be able to perform non-weapons missions for the military, such as extended duration intelligence collection). As a result, we expand the narrow definition of torpedo technology to include both self-propelled underwater weapons and small unmanned underwater vehicles.

Time Period Boundaries

We code torpedo technology as a single case study from 1871 to 2020. Robert Whitehead developed the first effective torpedo prototype in 1866; the weapon made its debut in 1871 when production of operational units began for the British Royal Navy.[1] Despite major improvements in torpedoes and the later introduction of unmanned underwater vehicles (UUVs), the distinguishability and integration of the technology remained relatively stable.

Torpedo, 1871–2020

Distinguishability: <u>High</u>

Torpedoes come quite close to being a purely military technology, as there are no direct civilian analogues. Some small unmanned underwater vehicles used for peaceful applications share similar design features and technologies. For example, the hull of the first unmanned underwater research vehicle developed in 1957 was shaped like a

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[1] For an excellent overview, see Katherine C. Epstein, *Torpedo: Inventing the Military-Industrial Complex in the United States and Great Britain* (Cambridge, MA: Harvard University Press, 2014).

torpedo and used the same basic propulsion system.[2] Yet torpedos are often highly distinguishable from UUVs across all four attributes.

First, despite sometimes sharing a hull with a torpedo shape, civilian UUVs look different because they are often outfitted with external sensors and robotic appendages to perform tasks, such as collecting marine samples or repairing underwater structures. Many modern UUVs have abandoned the torpedo shape entirely in favor of gliders with saw-tooth profiles or bionic structures that swim or crawl with robotic fins or crab-like claws. By contrast, torpedo weapons have a classical hydrodynamic streamlined shape and screw propellers because they are optimized to perform one task: deliver an explosive payload to the target. According to a report from the US Department of Defense, "The torpedo mission and undersea environment require a significantly unique design from other commercial or defense products."[3]

Second, military torpedoes follow a well-worn development pathway that privileges producing weapons at various weight classes with speed and stealth features to reach a target as quickly as possible while avoiding countermeasures. The vast majority of torpedoes are developed to move quickly over relatively short distances compared to civilian UUVs designed to perform long range and extended duration missions. Torpedoes have long been "produced in factories dedicated to military products," the Defense Department report underscored.[4] Indeed, the unique design requirements for making this technology useful in naval warfare "resulted in the establishment of a sector with specialized skills and facilities for torpedo development, production, and support."[5] There is little direct overlap between the development pathways for torpedo weapons and non-weapon UUVs.

Third, deployment patterns set military torpedoes far apart from civilian UUVs. As a weapon, torpedoes are launched out of identifiable tubes or other platforms to make them more effective in battle.[6] Civilian UUVs lack this type of tube launch system, as they are often just directly deployed from a mothership or research platform. There is no need to store UUVs in a steady state configuration so that they can be rapidly launched against targets in a hostile environment.

Fourth, it may be possible to quickly convert some civilian UUVs into weapons platforms by attaching an explosive payload to the system. But the utility of these converted systems is likely to be limited to bespoke missions, such as loitering around a

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[2] Salimzhan A. Gafurov and Evgeniy V. Klochkov, “Autonomous Unmanned Underwater Vehicles Development Tendencies,” *Procedia Engineering* 106 (2015): 142, https://doi.org/10.1016/j.proeng.2015.06.017.
[3] John Goodman, Tim Douglass, and Martin Meth, “Industrial Assessment for Torpedoes” (Washington, DC: U.S. Department of Defense, August 1995), i, https://apps.dtic.mil/sti/pdfs/ADA303815.pdf. In particular, the report noted that "torpedoes must have low radiated noise, high efficiency sonar systems, inertial reference systems, wide range depth sensing systems, embedded signal and tactical data processors, and high energy density non-air-breathing propulsion systems ... There are no equivalent system design requirements in the commercial sector nor in any other defense product segments,” 10.
[4] Goodman, Douglass, and Meth, 10.
[5] Goodman, Douglass, and Meth, 43.
[6] Some nonexplosive military UUVs with sensor packages share the same functional form and can be launched out of torpedo tubes.

target area for extended periods, as torpedoes need to be matched with launch platforms to be effective instruments of war.[7]

Integration: High (Military) / Low (Civilian)

Torpedoes are highly integrated within military enterprises for three reasons. First, torpedoes can be used in a wide range of operations as either a close attack or standoff weapon. This weapon may also be launched from many different military platforms, including large and small surface vessels, submarines, fixed-wing and rotary-wing aircraft, and land-based naval fortifications. As a result, torpedoes are an essential weapon system for almost all navies in the world. Second, the marginal cost of production is on par with other advanced conventional munitions, but certainly less than long-range missile systems. As the US Defense Department reported in 1995, "Torpedoes are designed to minimize production, operation and maintenance costs. Lightweight and heavyweight torpedoes typically cost between $500,000 and $1 million each."[8] By 2018, these costs increased to around $2.5 million per unit of the MK 48 Mod 7 CBASS torpedo (the standard heavyweight torpedo in the US Navy).[9] Third, advances in torpedo technology spillover into new use opportunities. For example, the development of passive and active homing systems coupled with long range heavyweight torpedoes created novel anti-submarine warfare tactics in the 1980s. In addition, developments in broader UUV platforms sometimes benefit torpedo weapons, as the underlying component technologies can be similar.[10] By contrast, similar technology in peaceful unmanned underwater vehicles (UUVs) remain isolated to performing limited industrial tasks or oceanographic research. The level of integration within the civilian economy is low because the range and variety of uses is narrow and the marginal cost of production is quite high.

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[7] "The physical design requirements of the torpedo are driven by load restrictions and launch requirements of the platforms that carry them," Goodman, Douglass, and Meth, “Industrial Assessment for Torpedoes,” 5.
[8] Goodman, Douglass, and Meth, 6.
[9] “Department of Defense Fiscal Year (FY) 2019 Budget Estimates: Weapons Procurement, Navy [Unclassified]” (Washington, DC: U.S. Department of Defense, February 2018), https://www.secnav.navy.mil/fmc/fmb/Documents/19pres/WPN_Book.pdf.
[10] "Although torpedo and UUV design requirements, functionality, and mission profiles areunique, some component technologies are similar. A number of component technology developments planned for UUVs could benefit torpedoes - intelligent controllers, depth sensing, high frequency transducer arrays, acoustic signal processing algorithms and architectures, advanced hull structures, silencing, energy sources, hydrodynamics, communications and inertial measurement. Even though some components are similar, UUV production is too low (five each year) to sustain capabilities that could support torpedo production," see Goodman, Douglass, and Meth, “Industrial Assessment for Torpedoes,” 11.

Outcomes

Agreements imposed on defeated powers. A set of treaties, the 1947 Paris Peace Treaties signed at the end of WWII, banned Axis states from having certain military capabilities. States could "not possess, construct or experiment with... torpedoes of non-contact types actuated by influence mechanisms, torpedoes capable of being manned... or motor torpedo boats."[11] Other torpedoes considered part of normal armament for naval vessels were allowed within the terms for naval vessels in the treaties. The production of "war material" which explicitly included torpedoes, was also limited by the treaties, and had to be handed over to the United States or Russia. For the treaty with Italy, storage and maintenance installations for torpedoes, sea mines, and bombs had to be dismantled or moved from islands to the mainland. These agreements do not include detailed terms on monitoring or verification, but these activities were given to representatives of the victor states (e.g., in the case of Italy, a Council of Allied Ambassadors from the US, UK, Russia, and France). Embassies of the states collected information on the implementation of the treaty provisions. The Allied nations were quite present on the ground in these defeated nations after the war, which enhanced their unilateral detection capabilities. With Romania, Hungary, and Bulgaria, the Soviet Union oversaw treaty implementation, and the United States and the United Kingdom undertook their own inspections.[12]

Incidents at Sea agreements (INCSEA) do not limit torpedoes themselves, but place a constraint on certain actions. Under these agreements, states agree to that, "Ships of the Contracting Parties shall not conduct simulated attacks by aiming guns, missile launchers, torpedo tubes or other weapons at ships or aircraft of the other Party."[13] The agreements include guidelines for how ships operating nearby should notify one another of a torpedo launching exercise, but do not include any additional provisions for how states can observe or monitor one another's behaviors.

Finally, an early agreement, the 1907 Hague Convention (VIII) Relative to the Laying of Automatic Submarine Contact Mines, focuses largely on specific types of sea mines, but also bans torpedoes that do not become harmless after missing their targets. It is not considered a significant limitation on torpedoes.[14] The agreement did not include any monitoring provision.

Theory Support: Neutral for H4. The verification measures in the post-war peace treaties were largely implemented with unilateral detection capabilities, though also with

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[11] "Draft Peace Treaties With Italy, Rumania, Bulgaria, Hungary, and Finland," *Foreign Relations of the United States (FRUS),* 1946, Paris Peace Conference: Documents, Volume IV, 1–5, https://history.state.gov/historicaldocuments/frus1946v04/comp1.
[12] Fred Tanner, United Nations Institute for Disarmament Research, and Graduate Institute of International Studies (Geneva, Switzerland), eds., *From Versailles to Baghdad: Post-War Armament Control of Defeated States* (New York: United Nations, 1992).
[13] See, for example, Agreement Between the Government of The United States of America and the Government of The Union of Soviet Socialist Republics on the Prevention of Incidents On and Over the High Seas.
[14] "Treaties, States Parties, and Commentaries - Hague Convention (VIII) on Submarine Mines, 1907," accessed January 17, 2022, https://ihl-databases.icrc.org/applic/ihl/ihl.nsf/INTRO/215.

some inspections on the territories of the states limited by agreement provisions. These more intrusive measures were notably imposed on states defeated in war. Within a few years, the United States and the Soviet Union also faced strong incentives to relax these rearmament restrictions as part of a competitive effort to make their respective allies and partners stronger. This outcome lends neutral support for our expectations about H4 because the role of technology is difficult to isolate in this case where post-war armament controls were imposed on defeated nation.