Introducing the COW Arms Technology Data, 1816-2023: Structure and Applications*

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Abstract

This article introduces a new global dataset tracking the adoption of 31 important arms technologies across all states from 1816 to 2023. Covering eight major categories – from small arms and artillery to combat helicopters and ballistic missiles – the dataset provides a comprehensive long-term view of the global evolution and diffusion of arms technology. We describe the conceptual foundations and coding procedures, as well as transformations of the final data relevant for scholars of international relations and comparative politics. We demonstrate the relevance of the data through three empirical applications: we show that arms technologies spread in ways consistent with the logic of the security dilemma; that technological superiority helps explain which states win wars, and that advanced arms help autocrats stay in power. These findings highlight the central role of arms technology in shaping both the global distribution of power and the durability of autocratic regimes.

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1 Introduction

Chairman Mao may have been overstating the case when he said that "political power grows out of the barrel of a gun" (Zedong 1954, 114), but with the caveat that there are other sources of power, the Chairman's proposition seems reasonable enough: According to Robert Dahl's famous definition "A has power over B to the extent that he can get B to do something that B would not otherwise do" (Dahl 1957, 202-203). Presumably, B is more likely to do something that B would not otherwise do if A has a gun (or one that is superior to B's). More generally, arms technology is a source of political power for those who possess it, and it shapes interstate relations, relations between states and subjects, and important societal outcomes. Without superior arms technology, it would have been impossible for a few small European countries to dominate the world from the 16th century until the Cold War (Diamond 1997; Hoffman 2015). Broader still, Van Creveld's sweeping history of warfare states that "war is permeated by technology and governed by it" (Van Creveld 2010, 1 and 311). Arms technology affects the advantage of a military offense against defense, the so-called "offense/defense balance" (e.g., Snyder 1984, Jervis 1978, and Van Evera 1984), the emergence and dynamics of international alliances (e.g., Morrow 1993), and the outbreak and outcome of intrastate conflict (e.g., Pamp et al. 2018, Mehrl and Thurner 2020). Arms technology also affects domestic politics and institutions. It increases the efficiency of the government's repressive machinery, eases the revolutionary constraint, and reduces the likelihood that rulers grant political rights (e.g., Hariri and Wingender 2024).

To facilitate the empirical study of the many ways arms technology affects, and is affected by, warfare, institutions, and politics more broadly, we introduce the Correlates of War (COW) Arms Technology Data. The data contain information on the adoption of 31 specific arms technologies in different countries and cover all states in the international system 1816-2023, as defined by Correlates of War Project (2017), as well as a summary measure of each country's overall level of arms technology.[1] The data are publicly available as a part of the Correlates of War database.

The COW Arms Technology Data complement existing resources on military capabilities. It is less detailed than some of the comprehensive databases on arms transfers and military inventories

[1] We use the term "arms technology" rather than "military technology" as some of the arms in our sample may be used by semi-militarized law enforcement units within the civilian police, domestic security forces, or gendarmeries.

that are available from the Cold War period and onward, such as the SIPRI Arms Transfers Database or The Military Balance. However, it offers researchers over 200 years of systematically classified arms technology data, enabling analysis without requiring expertise in specific weapon models. Other data sets on military capabilities over long time horizons, such as the COW National Material Capabilities dataset (Singer 1988, v6.0), track military personnel, military spending, steel production, and other capabilities that are distinct from technology.

In the first part of the paper, we outline the conceptualization of arms technology underlying the data set, our framework for selecting what technologies to include, and how we collected and processed the data. We then describe the coverage and structure of the final data set, and compare it to other data sets that researchers can use to study arms, arms technology, and military capabilities more broadly.

In the second part of the paper, we provide examples of how researchers can use the data in practice to study arms diffusion, success in warfare, and the durability of autocratic rule. These examples are chosen to illustrate the utility of different transformations of the data, and the practical considerations involved. The examples also show how the COW Arms Technology Data can contribute to scholarly debates at the intersection of international relations, comparative politics, and political economy. We engage with recent work in international relations on the determinants and consequences of military power, and offer an alternative to measures of military power based on broader material capabilities (e.g., Singer 1988; Gannon 2023). Moreover, our analysis speaks to a growing literature in comparative politics on autocratic stability and the role of coercive capacity in shaping autocratic regime resilience (e.g., Choulis et al. 2023, Hariri and Wingender 2024). Finally, by documenting the rapid, yet uneven, global diffusion of arms technology, we complement recent scholarship in political economy on technological dependency, arms transfers, and state-building (e.g., Fearon and Hansen 2018, MacInnes et al. 2024). While the analyses are merely suggestive and further research is needed to corroborate our findings, they do suggest the importance of coercive hardware in both international and domestic arenas.

2 Defining and measuring arms technology

The word ”technology” has several meanings in the social sciences. Orlikowski (1992), for example, distinguished between a narrow hardware-view, which encompasses ”the equipment, machines, and instruments that humans use in productive activities” (*ibid.*, 399), and a broader concept of social technology, which additionally includes the generic tasks, techniques, and knowledge used in production. We adopt the hardware-perspective, and define arms technology as a piece of equipment explicitly designed to kill, and potentially cause destruction of objects in the process.[2] The definition excludes less tangible social aspects, such as military organization and doctrine, and military hardware primarily designed for non-lethal uses, such as radar systems and communication systems.[3] To distinguish between technologies, we need a definition of technological *progress*, which we define as new varieties of arms with higher destructive capacity than earlier varieties. Progress can come from both vertical innovation – the introduction of more destructive versions of existing types of arms – and from horizontal innovation – the creation of completely new lines of arms. The first tank and the first military aircraft are horizontal innovations, whereas subsequent improvements (later generations of main battle tanks, for example) are vertical innovations. We use the distinction between horizontal and vertical innovation when we classify technologies below.[4] Technological progress arises from both gradual tweaks to existing designs and radical new innovations. Below, we focus on radical innovation to operationalize our definition of arms technology in a dataset spanning all countries over more than two centuries.

2.1 The technologies included in the dataset

Radical horizontal innovation, such as the first machine gun or the first tank, is easy to identify. The distinction between radical and gradual innovation is less clear in the horizontal dimension. To be included in our sample of technologies, we required that a vertical innovation led to a substantial

[2]This definition is standard (see, e.g., Boothby 2016, 4-5). As noted by scholar and Lt. Col. Justin McClelland, defining arms is a ”relatively straightforward process” (McClelland 2003).

[3]We consider new ways of bundling lethal and non-lethal technologies to be new arms technologies. In our framework, a machine gun mounted on a helicopter is a technology distinct from both the machine gun and the helicopter, for example.

[4]This distinction, now commonplace in economics, traces back to the Nobel Prize–winning contributions of Romer (1990) and Aghion and Howitt (1992), which demonstrate that growth can arise from horizontal innovation (new product varieties) and vertical innovation (quality improvements), respectively.

improvement in effectiveness as measured by objective criteria such as the rate of fire, reliability, or range, and that the superiority of the innovation manifested itself in widespread use.[5] One example of a technology fulfilling these requirements is the breech-loading rifle, which helped the Prussian army defeat the Danish and Austrian armies in the 1860s. Breech-loading not only sped up reloading, resulting in a rate of fire 3-5 times higher than what could be achieved with contemporary muzzle-loaders, it also allowed soldiers to reload in prone position, which significantly reduced the risk of being hit by enemy fire.

In addition to focusing on radical innovations, we limited the universe of potential technologies to be included to conventional land based and airborne arms. We disregarded naval technologies, which are less relevant for landlocked countries.[6] Within these boundaries, we asked five experts on military history and technology to identify radical innovations in arms from the past centuries.[7] Specifically, we asked them for a list of technologies that (*i*), made arms qualitatively different from earlier varieties, (*ii*), led to discrete improvements in effectiveness measured by objective criteria such as the rate of fire, reliability, or range, (*iii*), was either widely adopted or had otherwise significant impact on military history, and, (*iv*), that the consensus view among experts is that the technology fulfills (*i*)-(*iii*).

All the experts agreed on the final list reported in Table 1. In collaboration with the experts, we divided the 31 technologies into eight categories of arms: small arms, machine guns, artillery, tanks, fighter aircraft, combat helicopters, armed unmanned aerial vehicles (UAVs), and ballistic missiles.[8]

[5]Arms technological effectiveness is notoriously difficult to define and operationalize. Some dimensions of the overarching concept are measurable, such as range, rate of fire, payload, and reliability. Other dimensions are less easily quantified, including practicality, safety, and mission survivability. Note that adjacent concepts, such as "operational effectiveness" – the overall degree of mission accomplishment of an arms technology – implicitly depends on doctrine, tactics, and operational employment, all of which go beyond our narrow hardware definition of arms technology. We have therefore focused on the measurable dimensions of effectiveness, which pertain specifically to the arms technological hardware. See Hariri and Wingender (2024), Figure 1, for an illustration, which makes *effectiveness* operational for the category of small arms using the range and rate of fire.

[6]See Mahan ([1889] 2010, 43). On the offensive irrelevance for landlocked countries, see Crisher (2017, 2); for the defensive, see Grygiel (2021, 98). Scholars interested in naval power and technologies are encouraged to consult the Naval Power Dataset from Crisher and Souva (2014) or the rDMC data from Gannon (2023).

[7]The experts were: Ole L. Frantzen (military historian and former director ofThe Royal Danish Arsenal Museum), Kjeld Galster (military historian and former career soldier), Karsten Skjold Petersen (director of The Royal Danish Arsenal Museum), Simon Papousek (head of the Danish Defence Library), and Brian Krøjgaard (Warrant Sergeant at the R&D Armour branch, Danish Army Combat & Fire Support Center).

[8]Ballistic missiles were not included in the first version of the data, as the original purpose was to study domestic repression and civil war (Hariri and Wingender 2023, 2024).

The first technology in each category constitutes radical horizontal innovation: a completely new type of arm. Subsequent technologies within each category represent radical vertical innovation: they are strictly superior than their predecessors in terms of effectiveness, according to the experts we consulted. The superiority of the innovations is reflected in widespread use: older technologies are quickly replaced by newer ones in the same category after adoption, a fact reflected in both our sources and the descriptive statistics we present in the next section. In Hariri and Wingender (2023) we further show that each new type of small arm, machine gun, and artillery led to significant improvements in range and rate of fire (figures 1 and A1). Tanks and fighter aircraft are more complex technologies, which makes effectiveness hard to quantify. But thanks to international rivalries and technological progress, new models from arms producers in different countries arrived roughly at the same time, leading to the widely used classification of tanks, fighters, and combat helicopters into generations. Different classification schemes exist, but they only differ in minor details. We rely on the classification scheme in Zarzecki (2002).

Table 1: Arms technologies in the data set

Small arms	**Machine guns**	**Artillery**	**Tanks**
Flintlock musket	Hand-cranked	Field guns	Early tank
Percussion lock musket	Automatic	Rifled artillery	WWII tank
Minié bullet rifle		Steel tubes	1^{st} gen. battle tank
Breechloading rifle		Practical breechloading	2^{nd} gen. battle tank
Tubular magazine rifle		Recoil mechanism	3^{rd} gen. battle tank
Box magazine rifle			
Assault rifle			
Fighter aircraft	**Combat helicopters**	**Armed UAVs**	**Ballistic missiles**
Early aircraft	1^{st} gen. combat helicopter	Armed UAV	Short range
WWII era fighter	2^{nd} gen. combat helicopter		Intercontinental
1^{st} gen. jet fighters			
2^{nd} gen. jet fighters			
3^{rd} gen. jet fighters			
4^{th} gen. jet fighters			
5^{th} gen. jet fighters			

Notes: *This table shows the technologies in the COW Arms Technology Data sorted from least to most advanced within each category of arm (in bold).*

2.2 Measuring technology on the extensive margin

We collect data on technology adoption on the extensive margin, meaning that the final data set only records whether or not a given country in a given year uses each of the 31 arms technologies in our sample. Collecting data on technology adoption on the intensive margin, such as the number of machine guns owned by a government each year, would be infeasible as sources rarely mention quantities before the 20$^{\text{th}}$ century. Simply knowing whether a government had access to a given arms technology is informative, however. One reason is that once adoption of a new arm has begun, it quickly replaces earlier varieties. Unlike the decentralized adoption of civilian technology among many firms or households, the decision to adopt new arms is typically centralized within a single organization, like the military or police, for which standardization of equipment is often important. For example, Tsarist Russia adopted the Mosin-Nagant box magazine rifle in 1891, and within five years, two million copies were produced, equipping all Russian soldiers (Grant 2007).[9]

2.3 Measuring aggregate technology levels

The COW Arms Technology Data contain information on 31 specific arms technologies, but in some applications, researchers may need a single measure of a country's *level* of arms technology. Summarizing technology levels in a single number requires aggregation across diverse technologies, and consequently a range of both methodological and practical considerations. The challenge is least when aggregating within the eight broad arms categories, since the technologies are strictly hierarchical within each category A country with automatic machine guns is more advanced in the machine gun category than a country with only hand-cranked varieties, for example, and a country with hand-cranked machine guns is more advanced than a country with no machine guns at all. Therefore, within each category of arms, simply ranking countries according to their most advanced technology gives a correct ordering of their technology levels.[10]

Aggregating across arms categories adds complexity as there are no agreed-upon efficiency weights to apply across arms with different purposes. Whether a new type of tank is more important

[9] See Boix (2015, 159) for other examples of swift firearm adoption from early modern England, France, Poland, Russia, and Spain. The swift adoption of arms technology at the intensive margin relates to the organization of the military rather than the technologies themselves. Technologies that can be used both for civilian and military purposes tend to be adopted faster by the military both at the extensive and the intensive margin. Navies around the world replaced sail with steam much faster than merchant fleets (Hariri and Wingender 2024). Similarly, the British Navy Board ordered the application of copper sheathing to the first ships of the line in 1779, and by 1786 the entire Royal Navy was copper sheathed (Knight 1973). In comparison, just three percent of the merchant fleet registered by Lloyds of London had copper sheeting in 1786, and only 18 percent did by 1816 (Rees 1971).

[10] A cardinal measure of technology levels within arms categories requires assumptions about how much better than its precursors a given technology is, measured on some quantifiable scale (possibly based on some observable characteristics such as range, rate of fire, reliability, or caliber).

than a new type of small arm depends on the context. The challenge of constructing an aggregate measure of arms technology should not be overstated, however. It is no greater than the challenges that confront scholars measuring, e.g., democracy, economic freedom, human development, or any other complex concept in the social sciences. In fact, it may be smaller as most countries adopt the new technologies in roughly the order they were invented, even if the average speed of adoption varies across countries. One can consequently get a reasonable ranking of countries' arms technology simply by looking at the most recently invented technology in their possession. This approach is vulnerable to measurement error, however, but one can generalize the intuition by looking at how many technologies a country has adopted. We follow this simple approach in the empirical applications in Section 5.2 and 5.3, where we define the technology level of country i in year t as $I_{it} \equiv \sum_j d_{ijt}$, where d_{ijt} is a dummy that equals "one" if the state is currently using the technology, j, or if it is using a more advanced technology within the same category of arms.

Within our universe of technologies, I_{it} gives a correct ordering of arms technology levels if technologies are adopted in the same sequence in all countries. How accurately I_{it} tracks technology levels can consequently be assessed by measuring how similar adoption sequences are in our sample. We do so by comparing observations from different countries with the same value of the technology index $I_{j,t}$. In 48 percent of all such cases in our sample, the two countries have adopted exactly the same combination of technologies. In 89 percent, they differ by at most one technology (i.e., one of them has adopted technology X instead of technology Y). That countries adopt arms technologies in the same sequence is consequently a reasonable approximation, implying that I_{it} also is a reasonable proxy for arms technology levels. Moreover, even if two countries differ by one or more technologies, they might still have comparable technology levels if the technologies they do not share are equally sophisticated. What if the technologies in our sample are a subset of a larger universe of relevant arms technologies? I_{it} would in that case provide a correct ordering as long as the combined adoption sequence of both observed and unobserved arms technologies is identical across countries. While unverifiable, it does not appear to be an unreasonable assumption.

Depending on the context, I_{it} can be seen as both a formative and a reflective indicator of a country's aggregate level of arms technology.[11] I_{it} is reflective if the technologies in our data are

[11] In formative index construction, the individual indicators taken together cause or constitute the overarching concept, they are indicators of. In reflective index construction, the indicators are seen as the outcome of some unobserved, latent factor. The choice of measurement perspective is often straightforward because

regarded as a small sample of the set of arms technologies that contribute to the overall technology level. In that view, I_{it} would reflect an underlying and unobserved technology level. If one considers the technologies in our data set the full population of relevant technologies, I_{it} would be a formative index, implying that countries are only technologically advanced to the extent that they have adopted the technologies in our database.

All in all, we consider the index I_{it} a convenient, transparent and informative way to aggregate arms technologies to the country level and provide the index as a separate variable. Yet, depending on the research question, one might wish to construct more sophisticated indices of technology, or aggregate them in various ways to measure other concepts related to countries' military power or their coercive capacity. For instance, Hanson and Sigman (2021) argue that state capacity – of which coercive capacity is one dimension – can be seen as a latent phenomenon, for which they construct a reflective measurement model. Taking the formative view, one could also adopt a production function-approach in which one would assume or estimate a "productivity level" of each technology as well as the elasticities of substitution between them.

3 Data collection and processing

This section provides an overview of our data collection process, the sources we consulted, information on coverage, and a comparison to related data sets. Additional information is available in the online appendix. We begin by clarifying the terminology we use below:

- A technology is "used" by a state in a given year if it was part of the regular armament of at least one military unit, or in some other branch of the government (we elaborate on how we assess this below).
- A technology is "adopted" in the first year in which it is used, according to the definition above.
- A technology is "superseded" if the state currently uses a superior technology within the same category of arms.

the causal priority between the underlying concept and the indicators is clear. In other cases, "the directionality of the relationship is far from obvious" (Fayers and Hand 1997, p. 393). This is the case here, and coercive capacity and related concepts can meaningfully be quantified using both a formative and reflective measurement model depending on the research question at hand.

- A technology is "not used" in a state if it is not currently used or superseded, according to the definitions above.

Many of our sources for the early period are qualitative, so we often rely on information on how arms were acquired and used, possibly combined with indefinite quantifiers. For instance, we would regard the box-magazine rifle as in use if sources indicate that it was introduced as the infantry's service rifle, even without information on the quantities involved. In other cases, the sources may describe that a given arm in stock was an experimental prototype, a test specimen supplied to the government by an arm producer, or acquired solely for training or ceremonial purposes. In such cases, the arm should not be considered in use, according to our definition. If we do not have such explicit qualitative information, we assume that an arm is not intended for regular use if just a few are acquired. For small arms, we apply a slightly stricter standard and record them only if they have been issued as the standard weapon for a military unit of size comparable to a company.

For each of the 31 technologies, we sought to identify the adoption year in each independent country. When information on the adoption year was unavailable – whether because adoption had not yet occurred in 2023, the country already possessed the technology at independence, or the sources were too vague to assess it – we recorded the earliest year in which a technology *was* used and the latest year in which it was *not* yet used. When sources are too vague, this approach leaves a gap with no information on technology use, which results in a few missing observations in the final data set.

3.1 Sources

The diffusion of arms after 1950 is reasonably well documented in existing databases, notably the SIPRI Arms Transfers Database, The Military Balance, and the data appendix to Zarzecki (2002). To obtain data for the years before 1950, we consulted a wide range of different sources. Among the primary sources were declassified reports on foreign military capabilities delivered to the British, German, and American governments, trade registers of arms producers, such as Colt, Krupp, and Lithgow Arms, and historical newspaper articles on arms deals. Secondary sources included various statistical yearbooks, such as Almanach de Gotha (issues 1840-1923), Stateman's Yearbook (issues 1864-1923), the League of Nations' Armament Yearbook (1924-1940), the IPITA data set (Mehrl and Thurner 2025), and a wide range of scholarly works on military history. In total, the COW Arms Technology Data Set is based on information from more than 500 different sources. The full list of sources, broken down by country-technology pairs, can be found in the online documentation accompanying the data set.

3.2 Assumptions

Empires have disintegrated and new states emerged in the two centuries covered by the data set. Obtaining information about arms technology around state formation can be challenging. In cases when we have no other information regarding which arms were present at independence, we augment the raw data with a few mild assumptions:

- When a state fragments, we assume that the political unit containing the old capital maintained the technology level of the former state.
- When a war of independence is won, we assume that the newly independent state retained the arms used by the pro-independence side during the war.
- When states are unified, we assume that the resulting political unit has access to all technologies possessed by the predecessor states.
- When an arms technology has been universally adopted by all countries around the world for a certain period, we assume that newly independent states also possess it (unless we know otherwise). In practice, we assume that after 1945, all newly independent states were equipped with box-magazine rifles and machine guns, and that any observed artillery was recoilless. Furthermore, we assume that states achieving independence after 1990 were armed with assault rifles.

3.3 Structure and coverage of the data set

The COW Arms Technology Dataset is a three-dimensional panel with annual observations of the 31 technologies across all states in the international system, as defined by the Correlates of War Project (2017), excluding current states with less than half a million inhabitants as of 2016.

Among the excluded states, only Brunei and Malta have a military force. We include historical states irrespective of population size.

We code a state-technology-year triplet as "1" in a given country in a given year if the technology in question was used in the military or other branches of the government. "Adoption" is then the first such year in a given country. We code it as "0" if the technology is not currently used or currently superseded by a superior technology within the same arms category. We code it "9" if it is superseded by a superior technology. Missing observations are coded as such.[12]

To illustrate the coding, consider the French army, which adopted its first breech-loading artillery in 1877. We code breech-loading artillery as "0" in France until 1877 and as "1" from 1877 to 1897. From 1898, when the French army adopted the recoilless Canon de 75 modéle 1897, we code breech-loading artillery as "9".

The three dimensional Arms Technology Data Set consists of 505,951 data points, of which 0.4 percent are missing observations due to lack of accurate information in our sources. Most missing observations are for Latin American countries in the 19$^{\text{th}}$ century. Another way to assess the data coverage is to consider the 5,664 state-technology combinations in the data.[13] For 96.2 percent of these pairs, we either know the exact year in which the technology was adopted by the state, whether it was adopted before our sample period, or whether it had yet to be adopted by the end of our sample period. For the remaining 3.8 percent, we know that adoption took place within a certain interval of years, which in more than half of the cases is shorter than five years.

3.4 Related databases

Table 2 compares the COW Arms Technology Data set to other readily available databases with a global scope that scholars can use to study military capabilities. They fall into three broad categories: databases on military inventories, databases on arm transfers across borders, and databases on military capabilities beyond technology. As the COW Arms Technology Data presented here, the Disaggregated Military Capabilities data set (rDMC) of Gannon (2023) falls in the first cat-

[12] Our coding rules ignore technological regress. Technological regress is rare, although a few examples exist, such as Costa Rica, which disbanded its army in 1949 and gave up all arms except the small arms used by its police force.

[13] The dataset contains 6,014 state–technology pairs in total, but we here omit cases in which the technology was developed after the state in question had ceased to exist. For example, pairs involving tanks in the Kingdom of Two Sicilies are omitted.

egory. The rDMC data are drawn from the annual International Institute for Strategic Studies (IISS) Military Balance reports. The data report stocks of major weapon systems and a range of other military equipment, including sensors and engineering assets. Such detail comes at the cost of temporal coverage, however, and the rDMC data are only available for the period 1970–2014.

Data sets on international arms transfers also offer a high level of detail. The SIPRI arms transfers database, for instance, contains records of almost all transfers of major arms systems between 1950 and 2024 (SIPRI n.d.), including the identity of both the supplier and the recipient, the specific models, their numbers, and their estimated production costs. NISAT (2017) has a similar dyadic structure, but focuses on small arms and light weapons in the period 1962-2015. And finally, the Interwar Period International Trade in Arms (IPITA) database tracks arms transfers among members of the League of Nations in the period 1920-1939. These datasets are well suited for examining the determinants and consequences of international arms trade, but they do not include information on domestically produced arms.

The COW National Material Capabilities Data Set (Singer 1988, v6.0) is an example of the third approach to measuring military capabilities. Rather than focusing on specific arms or arms technologies, it provides a Composite Indicator of National Capabilities (CINC), a measure of countries' material capabilities. It is based on six components, including military expenditure and military personnel. Souva (2023) provides a more targeted measure of material military power based on both military expenditure, personnel, and stockpiles of arms.

4 Descriptive patterns

To illustrate the structure and content of the COW Arms Technology Data, we here present selected descriptive statistics on arms technologies over time and across regions. Figure 1 begins by plotting "use" by technology, year, and the number of users. In the figure, we assume that countries no longer use a given technology when a more advanced arm of the same type has been adopted.[14] When reading the figure, note that the number of potential users is higher towards the end of the sample period as there were more independent states.

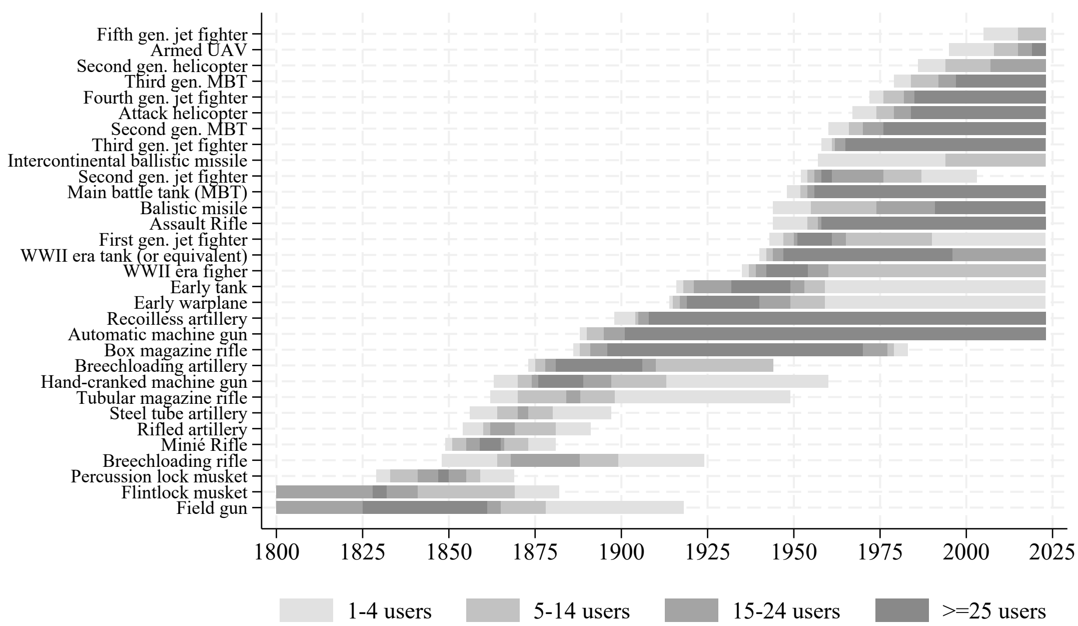
One thing that stands out in Figure 1 is the rapid arrival of new arms technologies in the

[14] Obsolescence defined this way is indicated by the "use" variable taking the value 9 in the data set, so the shaded areas represent the number of countries for which we code use as 1; see Section 3 above.

Table 2: Overview of data sets on arms and military capabilities

Name	Type	Details	Period	Source
COW Arms Technology	Inventories	Technology adoption at the extensive margin. Covers 31 land-based and airborne arms technologies.	1816–2023	This paper
rDMC	Inventories	Lists inventories of a range of military equipment classified into types. Does not include small arms. Derived from the IISS *Military Balance* reports.	1970–2014	Gannon (2023)
SIPRI arms transfers	Transfers	Dyadic data on all international transfers of major conventional arms systems.	1950–2024	SIPRI (n.d.)
NISAT	Transfers	Dyadic data on international transfers of small arms and light weapons.	1990–2015	NISAT (2017)
IPITA	Transfers	Dyadic data on international transfers of major conventional arms systems. Cover members of the League of Nations during the interwar period.	1920–1939	Mehrl and Thurner (2025)
COW National Material Capabilities	Capabilities	Information on total population, urban population, iron and steel production, energy consumption, military personnel, and military expenditure, and a composite indicator of national capabilities (CINC) based on these capabilities.	1816–2016	Singer (1988)
Material Military Power	Capabilities	Provides a composite index of military power based on both possession of arms technology, military expenditures, and military personnel	1865–2019	Souva (2023)

Figure 1: Users by technology and year

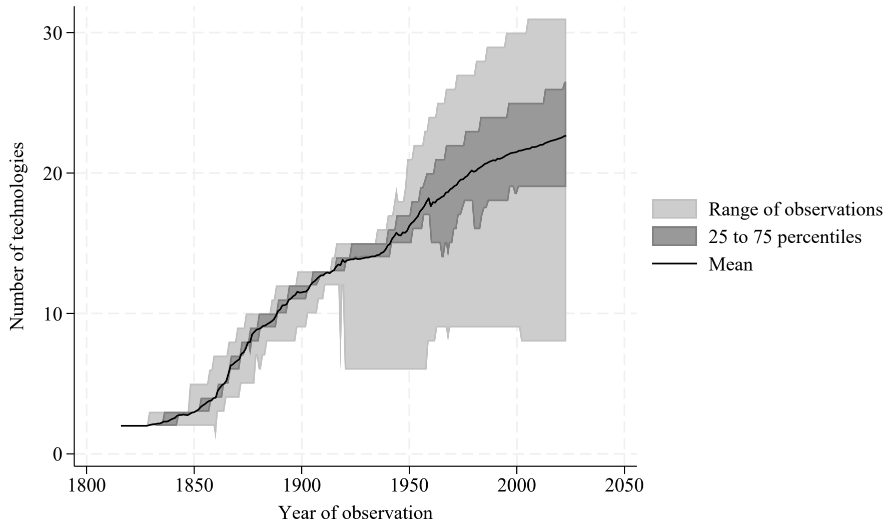


Notes: *The figure shows the number of states in the international system, as defined by Correlates of War Project (2017), that used a given arms technology in a given year. See Section 3 for the definition of "use".*

second half of the 19th century, an acceleration in technological progress reflecting that the tools and technologies of the Industrial Revolution began to be applied to arms production on a large scale (Krause 1992). Moreover, the figure shows that technological breakthroughs in arms technology tend to occur during periods of great power conflict, as evidenced by the surge of innovations around World War II and the early Cold War. These trends are also visible in Figure 2, which plots the number of arms technologies adopted by an average country along with two measures of the dispersion of arms technology: the interquartile range, and the full range of observations. The dispersion in arms technology was limited in the early 19th century, reflecting both the rapid diffusion of arms technologies documented in Hariri and Wingender (2024), and the fact that the international system at the time consisted of fewer and more homogeneous states than it does today. The sharp decline in the lower bound of technology use in 1920 reflects the inclusion of all League of Nations members in the COW definition of the international system, resulting in a more heterogeneous sample of states in terms of economic development and state capacity. Decolonization increased heterogeneity further throughout the twentieth century. Other reasons for the greater dispersion in arms technology in the postwar period include more expensive technologies, such as tanks and fighter aircraft, and the bipolar alliance pattern after World War II, which allowed smaller countries to heed the security imperative by allying with a super power instead of building domestic military capacity.

Figure 3 plots the average adoption of arms technologies across six world regions. To reduce noise from outliers, we only include regions when they contain at least eight independent states. The close co-movement between Western Europe and Latin America up to World War II is noteworthy as it clearly illustrates the rapid diffusion of arms technologies. After the fall of the Iron Curtain in 1989, the average Eastern European country fell behind countries in the West and in the Middle East and North Africa. The initial drop reflects a composition effect as the former Soviet and Yugoslav republics emerged with relatively modest inventories of military equipment. However, the subsequent stagnation of arms technology in Eastern Europe may be attributed to the reduced geopolitical tensions in the decades after the Soviet Union fell apart and a tendency of Eastern European countries to outsource part of their defense to other NATO members (trends that have recently been reversed). By contrast, persistent geopolitical instability in the Middle East, coupled with oil wealth, has driven rapid adoption of arms technologies in the region. This constitutes a

Figure 2: Average adoption and dispersion of arms technology



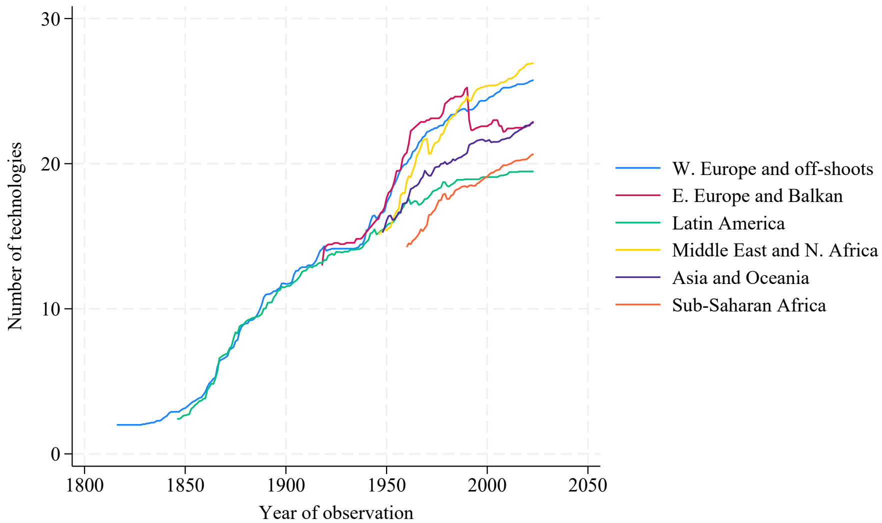
Notes: *The figure shows the average number of arms technologies adopted among members of the international system as defined by Correlates of War Project (2017), along with the interquartile range and total range of observations by year.*

technological complement to Bellin (2004), who finds that Middle Eastern countries are exceptional in their overall repressive capacity.

5 Applications

In this section, we demonstrate how the COW Arms Technology Data Set can contribute to ongoing debates in political economy, comparative politics, and international relations. We focus on the drivers of arms technology adoption, success in warfare, and autocratic survival. These three applications were chosen not only for their substantive relevance to scholars in IR, comparative politics, and political economy, but also because they allow us to illustrate three transformations of the dataset that may be useful in other settings. We keep the analyses simple, as our main aim is to demonstrate the usefulness of the data. The findings we present below are suggestive, but they do indicate that it is relevant to use the COW Arms Technology Data Set to pursue further analysis of arms technology adoption and of how arms technologies shape warfare and domestic politics.

Figure 3: Average adoption by world region



Notes: *The figure shows the average number of arms technologies adopted over time by world region. Averages are computed for regions with at least eight independent members of the international system of states as defined by Correlates of War Project (2017).*

5.1 The Diffusion of Arms Technology

Patterns of technology diffusion are remarkably consistent across different technologies. A key empirical regularity is that plotting the share of technology adopters among potential users over time typically yields an S-shaped curve.[15] Figure 4 shows that the diffusion processes of five arms technologies, representing different time periods and categories of arms, all followed this pattern.

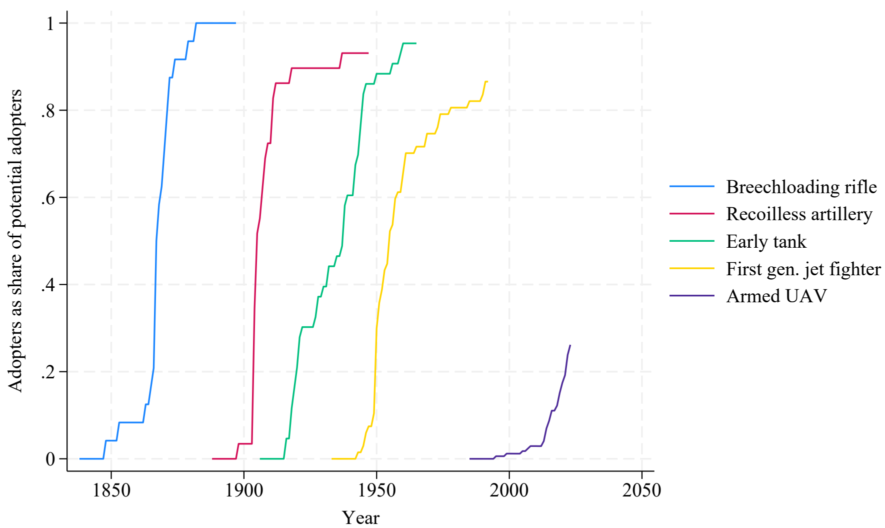
The earliest of the five technologies is the breech-loading rifle, pioneered by Prussia, and only adopted by a few of Prussia's allies before the technology proved to be superior to muzzle loaders in the wars against Denmark (in 1864) and Austria (in 1866). Other countries took notice, and by 1870, only a few states had not yet adopted the new technology, as indicated by the steep S-curve for breech-loading rifles. Some purchased the new rifle directly from Prussia, but many others developed their own inspired by the Prussian design. Herein lies a general point: cross-border technology diffusion occurs through both the movement of physical goods and the spread of intangible ideas, which are then applied in domestic production.

The S-curves for the other four technologies in Figure 4 look similar to that of breech-loading rifles, but do not reach an adoption share of "one" in the fifty years-window considered. One reason

[15] See Griliches (1957) for a seminal contribution, and Horowitz (2010) for arms diffusion.

is that rifles (per unit) are much cheaper than artillery, tanks, and fighter aircraft. Some countries, especially small ones, have therefore chosen not to adopt them, relying instead on alliances or remoteness for security. Whether the adoption share of armed UAVs will reach one within 50 years remains to be seen.[16]

Figure 4: S-curves, selected technologies



Notes: *This figure plots the share of countries that have adopted a technology. To avoid noise from states entering or leaving the international system, we balance the sample for each technology in the fifty years after its first adoption by any state.*

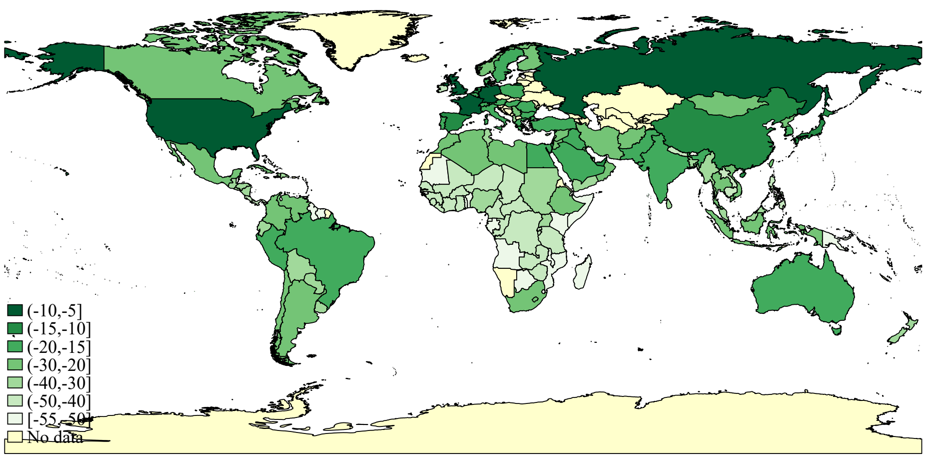
Another common approach to studying technology diffusion is by means of adoption lags (see, e.g., Comin and Mestieri 2014). An adoption lag is the time between a technology is first adopted anywhere until it is adopted by a given user. In 1898, for example, France became the first country to adopt recoilless artillery (the Canon de 75 modèle 1897). Germany followed in 1904 (Krupp 7.5 cm model 1903), making the adoption lag for recoilless artillery in Germany $1904 - 1898 = 6$ years.

Adoption lags are unobservable in countries that have not yet adopted a given technology. Researchers must either omit such instances from the analysis, or assume an adoption lag of some specified length. Here, we provide examples of both approaches along with some practical considerations. The first example is the map in Figure 5 in which countries are shaded according to their average adoption lag over the period 1816-2023. The averages are based on all technologies in the data, except those widely adopted at the beginning of the sample period (flintlock muskets and

[16] See Horowitz (2020) for an overview of the proliferation of military drone technology.

field artillery), and those currently in the early stages of diffusion (armed UAVs, fifth generation jet fighters, and intercontinental ballistic missiles). For each country, we omit all technologies invented before it joined the international system. The sample restrictions mean that we observe few, if any, adoption lags in many of the countries that gained independence in the second part of the 20$^{\text{th}}$ century. Their average adoption lags are therefore either missing or susceptible to outliers. To provide a comprehensive picture that includes such countries, we assume an adoption lag of 50 years for technologies that were not adopted at the end of the sample period. For consistency, we also truncate observed adoption lags at 50 years. The resulting map in Figure 5 clearly shows the technology frontier in Western Europe plus Russia and the United States. The average adoption lags for the frontier countries are between five and ten years, reflecting that technological leadership within the frontier group has changed over the two centuries, with Prussia/Germany being in the lead in much of the 19$^{\text{th}}$ century, and the United States in most of the 20$^{\text{th}}$.

Figure 5: Average adoption lag by country, 1816-2023



Notes: *Darker shading indicates faster adoption. Adoption lags are truncated at 50 years. Armed UAVs, 5th-gen fighters, and ICBMs are omitted due to limited diffusion at the end of the sample period, and flintlock muskets and field guns are omitted due to widespread diffusion in the beginning. States gaining independence after the Cold War ended are excluded.*

To further explore cross-country variation in the speed of arms technology adoption, we run the following regression with adoption lags as the outcome:

$$Adoption\,lag_{i,j} = \alpha_i + \alpha_j - \boldsymbol{\beta}'\mathbf{X_{i,j}} + \varepsilon_{i,j}. \tag{1}$$

The unit of observation is technology j observed in country i. We omit the same technologies as in Figure 5, and additionally exclude non-adopters rather than assuming an adoption lag of 50 years. The country-technology panel structure of the data provides more observations than in the example with average adoption lags, which reduces the sensitivity to outliers. It also allows us to include technology-fixed effects, α_j, and country-fixed effects, α_i, which reduce other forms of biases that might arise from omitting non-adopters. The technology-fixed effects also control for unobserved factors intrinsic to the technology, such as unit costs, as well as for factors pertaining to the period when the technology diffused, such as extraordinary rapid diffusion caused by a World War. The matrix $\mathbf{X}_{i,j}$ contains a range of potential determinants of technology adoption measured in the year technology j was first adopted anywhere. We measure all the factors contained in $\mathbf{X}_{i,j}$ using dummy variables, and multiply the entire term $\boldsymbol{\beta}'\mathbf{X_{i,j}}$ by minus one. A given coefficient in the vector β can therefore be interpreted as how many years faster a country adopts technology if it fulfills the requirement for scoring a "one" on the associated dummy. As usual, $\varepsilon_{i,j}$ represents the error term.

We include five determinants of arms adoption in the model. The first is a dummy for whether a country was at war within the first ten years after a technology was invented, according to the COW War Data (Sarkees and Wayman 2010). Second, we include a dummy for whether a neighboring state adopted the technology within the first ten years after it was first introduced. We define neighbors as states that share a land border or are within 24 miles of each other across the sea according to the Correlates of War Direct Contiguity Data Set v.3.2 (Stinnett et al. 2002). Third, we include a dummy for whether a state had national material capabilities above the global median in the year of introduction according to the Correlates of War data set of the same name (Singer 1988, v6.0). Fourth, we include a dummy for whether a state had GDP per capita above the global median, using data from the Maddison Project Database (Bolt and van Zanden 2024). Finally, we include a dummy for whether countries were democratic in the year of invention according to the Boix et al. (2013) democracy indicator v4.0.

We first run the regression in equation (1) one correlate at a time without country fixed effects. The results, reported in columns (1)-(5) of Table 3, show that all five determinants are individually statistically significant and associated with between four and seven years of faster technology adoption. Because they are correlated with each other, the coefficients fall somewhat when we include them together in column (6). The coefficient on democracy drops the most and turns insignificant, most likely because of democracy's positive correlation with GDP per capita and geographical proximity to the technology frontier in Western Europe.[17]

When we add country fixed effects to the regression, only the coefficients on warfare and adoption among neighbors remain significant. Not because material capabilities and GDP per capita are unimportant, but because the ordering of states in these dimensions does not vary much over time. Most variation in these variables is therefore absorbed by the fixed effects. What column (6) tells us, then, is that in the short run, war and the security threat posed by a better-armed neighbor appear to be the primary determinants of arms technology adoption. These findings align with the logic of the security dilemma (e.g., Jervis 1978), in which countries cannot ignore the risk that neighboring states might use their arms offensively, even if they were originally adopted for defensive or domestic purposes.

Table 3: Correlates of arms technology adoption

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Warfare	5.09***					3.04***	2.52***
	(1.18)					(0.97)	(0.87)
Adopted by neighbor		6.93***				3.10**	2.12*
		(1.37)				(1.16)	(1.12)
Above median material capabilities			7.60***			4.99***	1.31
			(1.08)			(0.85)	(1.22)
Above median GDP per capita				6.38***		4.33***	-0.86
				(1.13)		(0.92)	(0.93)
Democracy					4.43***	1.31	-0.42
					(1.53)	(1.23)	(1.44)
Observations	1,123	1,123	1,123	1,123	1,123	1,123	1,097
R-squared	0.26	0.26	0.31	0.29	0.25	0.36	0.53
Technology FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State FE	No	No	No	No	No	No	Yes

Notes: *"Adopted by neighbor" equals 1 if a neighboring state adopted the technology within 10 years of its invention. "Warfare" is 1 if country i was at war in that period. GDP per capita and material capabilities are 1 if above the median at the time of introduction. National material capabilities is a composite index of total population, urban population, iron and steel production, energy consumption, military personnel, and military expenditure. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1*

[17] In analyses of bilateral arms trades, Akerman and Seim (2014) and Comola (2012) find that differences in political regimes are significantly negatively related to arms transfers during, but not after, the Cold War and that democracies tend to both import and export more arms than autocracies.

5.2 Interstate war

This section uses the COW Arms Technology Data to study the outcome of wars.[18] We use interstate wars as the unit of observation in cross-sectional regression with a dummy indicating whether the initiator won the war as outcome and a dummy indicating whether the initiator had more advanced arms than the target as the main explanatory variable.[19] The results allow us to identify any positive correlation between possessing more advanced arms and winning wars, with the coefficients providing approximate probabilities.

To determine which country was more advanced, we use the simple ordinal index I_{it}, discussed in Section 2.3, which counts the number of arms technologies country i has adopted in year t. We use the same sample of wars as in the previous section, but obtain information about belligerent parties and dyadic outcomes from the COW Directed Dyadic Interstate War Dataset Version 4.0 (Maoz et al. 2019).

As a first step, we regress the dummy for winning on a constant. The result, reported in column (1) of Table 4, shows that the aggressors won 69 percent of the wars in the sample. Countries are more likely to start a war when they expect to win. In column (2), we add a dummy for whether the aggressor had more advanced arms technology than the target country one year before the onset of the war.[20] The estimated coefficients show that the aggressors' odds of winning are better precisely because they tend to have more advanced arms than their targets: aggressors with superior arms technology win 88 percent of the wars they start, whereas aggressors with inferior arms only win 48 percent.

As documented in Table 3 above, advanced arms technology is correlated with regime type, wealth, and broad material capabilities, factors that scholars of war have long debated the relative merits of as explanations for success in warfare (e.g., Desch 2002, Henderson and Bayer 2013, Reiter and Stam 2003; Rosen 1972). Rosen, for example, found that the wealthier side won almost 80 percent of the interstate wars (Rosen 1972). Other scholars have argued that democracies are

[18]See Bas and Coe (2012) for a model of how arms technology affects the occurrence of war.

[19]We code draws as 0.5, and the dummy for arms technology as 0.5 when the initiator and the target are equally advanced, such that estimated coefficients can be interpreted as in a linear probability model. While some countries fight multiple wars in our sample, many do not. We are consequently unable to use panel data methods here.

[20]In cases with multiple aggressors and/or targets, we use the technology level of the most advanced state. We exclude states that joined the war later on.

particularly apt at selecting "winnable" wars (e.g., Reiter and Stam 2010), at fighting wars (e.g., De Mesquita et al. 2005), or both (Reiter and Stam III 1998). Lastly, of course, scholars in the realist tradition argue that states with greater relative military capabilities are more likely to win their wars (e.g., Desch 2002).

We add control variables to the regression to document that arms technology is distinct from other determinants of victory. In column (3) of Table 4 we add a dummy for superior material capabilities. This reduces the coefficient on superior arms technology, but it remains sizable and statistically significant. Moreover, superior arms technology is associated with a higher estimated probability of winning a war than having superior material capabilities.[21]

In columns (4) and (5), we control for democracy, respectively with and without controlling for superior material capabilities, using a variable that takes the value 1 if a democracy attacks an autocracy, -1 if an autocracy attacks a democracy, and 0 if the two parties have the same regime. The coefficient on democracy can consequently be interpreted as the approximate conditional probability that democracies win against autocracies relative to the outcome when the fighting parties have the same type of regime, a probability we estimate to be 12 or 13 percent depending on whether we control for material capabilities. Adding democracy to the regressions only reduces the estimated effect of arms technology slightly. While these results provide some support for the so-called "democratic victory thesis" (e.g., Lake 1992, Reiter and Stam 2010), they also suggest that democracies excel at war, in part, because of their superior arms technology. Without conditioning on arms technology, the coefficient on democracy would be 0.19 and statistically significant at the one percent level.

The analysis of technology diffusion above showed that arms adoption often takes place in times of war, so in column (6), we include a dummy indicating whether the initiator adopted more arms than the target during the war. Unsurprisingly, adopting more arms than one's opponent is associated with a higher probability of winning.

[21] GDP data are only available for both the initiator and the target of a war in 66 of the 101 cases. The small sample size presumably explains why the coefficient on GDP is insignificant when included in the model. Superior arms technology remains statistically significant with $p = 0.04$ when controlling for GDP, even in the smaller sample.

Table 4: Arms technology and success in warfare

	(1)	(2)	(3)	(4)	(5)	(6)
Constant	0.69***	0.48***	0.43***	0.51***	0.46***	0.29***
	(0.04)	(0.06)	(0.07)	(0.07)	(0.07)	(0.10)
Superior arms technology		0.40***	0.29***	0.35***	0.23**	0.31***
		(0.10)	(0.11)	(0.10)	(0.11)	(0.11)
Superior material capabilities			0.22**		0.23***	0.20**
			(0.08)		(0.08)	(0.08)
Democracy vs. autocracy				0.12*	0.13**	0.14**
				(0.07)	(0.07)	(0.07)
Faster growth in arms tech.						0.27**
						(0.13)
Observations	101	101	101	101	101	101

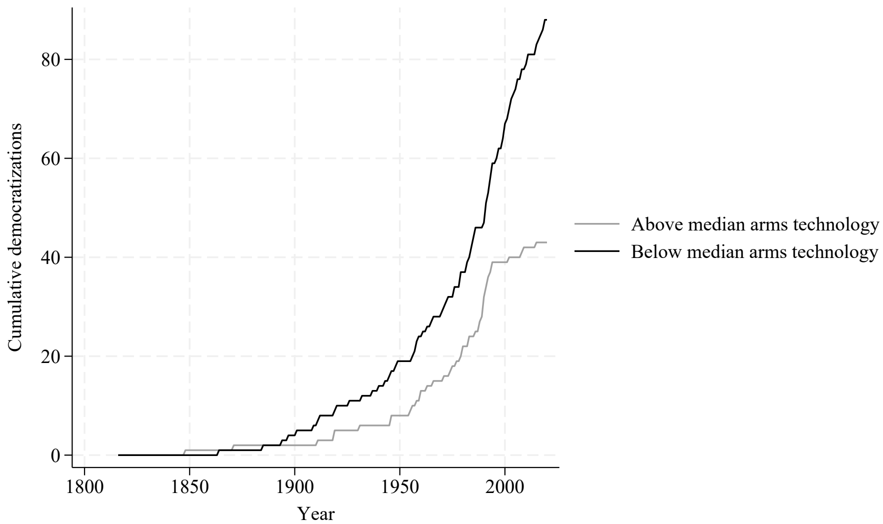
Notes: *Draws coded as 0.5. "Superior arms", "material capabilities", and "faster growth" are dummies for initiators more advanced than targets one year before onset (0.5 if equal). "Democracy vs. autocracy" is the difference in regime type per Boix et al. (2013); its coefficient reflects the added win probability for democracies. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.*

5.3 Autocratic survival

Incumbent leaders not only face threats posed by other states. Here, we focus on "the threat from below" – the threat that masses pose to autocratic survival (Svolik 2012). Repression of the masses is made cheaper and easier by having access to advanced arms technology, and the government's possession of overwhelming military force may silence demands for reform from being voiced at all. Consistent with this view, Figure 6 shows democratization is less likely in countries with relatively advanced military arms. In every year, we split countries classified as autocracies by Boix et al. (2013) into two equally sized groups based on whether they, conditional on their GDP per capita, have adopted more or fewer military technologies than the median autocracy in that year. We condition on GDP per capita to account for the modernization hypothesis. Over the entire period from 1816, democratization was twice as frequent among autocracies with less advanced arms technology (the samples of above/below median-countries are updated every year, so they are by construction of the same size in all years). Interestingly, most of the difference originates before World War II and after the fall of the Iron Curtain in 1989, suggesting that the dynamics might have been different during the Cold War.

In Hariri and Wingender (2023), using an earlier version of our data, we show that the pattern in Figure 6 is likely causal, and driven by an increased ability of incumbent autocrats to suppress resistance. These findings complement Albertus and Menaldo (2012), who document that army size is negatively associated with transitions to democracy. Arms technology helps to protect authoritarian leaders from other internal threats as well. In Hariri and Wingender (2023), we find that advanced arms reduce the likelihood of all forms of regime change – except military coups.

Figure 6: Democratization and arms technology



Notes: *The figure shows the cumulative number of democratizations in countries with more/fewer technologies than in the median country in any given year. We condition on GDP per capita in the median split. Samples are updated yearly to include the same number of observations. Data on democratization are from Boix et al. (2013) v4.0, and GDP data are from Bolt and van Zanden (2024).*

6 Conclusion

Reflecting on the state of social science research, Adam Przeworski once lamented that "we still do not know why people with guns obey people without them."[22] The COW Arms Technology Data Set 1816-2023 allows researchers to explore this and many other questions in a systematic and quantitative fashion: To name but a few fundamental examples, arms technology shapes the relationship between states and subjects, and it shapes the relation between states, whether these are allied or at war. Arms technology, in short, is relevant for students of international relations, comparative politics, political economy, and the social sciences more broadly.

[22] Quoted in Munck and Snyder 2007. About a decade later, Przeworski wrote: "I am still obsessed by the question of why people with guns obey people without them" (Przeworski 2016, 10).

Even so, systematic evidence on arm adoption across countries and over long historical periods has been limited. Existing data sources mostly focus on specific weapons systems, international arms transfers over shorter periods, or more aggregate measures of overall capabilities. These data have greatly advanced research, but provide only partial insight into states' adoption of major arms technologies, the drivers and consequences of these, and how these adoptions spread across the international system. The COW Arms Technology Data Set 1816-2023 is designed to fill this gap by providing a systematic and historically comparable measure of the adoption of key arms technologies across countries and over more than two centuries.

The COW Arms Technology Data Set records the adoption of 31 major land-based and airborne arms technologies for all states in the international system from 1816 to 2023. Organized as a three-dimensional country-technology-year panel, it allows researchers to study diffusion at multiple levels of aggregation, from individual technologies to broader categories of arms and overall levels of technological sophistication. Its principal strengths are its global scope, long historical coverage, and high degree of completeness: the dataset contains more than half a million observations with only a tiny fraction of missing values.

Using simple empirical frameworks, we have shown in this paper how arms technology diffuses swiftly across countries in a way consistent with the logic of the security dilemma. We showed that arms technology is closely linked to successful warfare and that it helps to explain why democracies tend to excel in war. We also showed that advanced arms technology tends to stabilize autocratic regimes. Together, these findings underscore the central role of coercive technology in shaping both the international distribution of power and domestic political regime developments. More in-depth analysis using the COW Arms Technology Data Set could shed further light on these important issues.

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