A new data set on arms technology adoption 1816-2023*

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Abstract

This article introduces the COW Arms Technology Data Set, documenting the adoption of arms technology across all states in the international system from 1816 to 2023. The data include 29 specific arms technologies categorized into seven broad groups: small arms, machine guns, artillery, tanks, aircraft, helicopters, and armed UAVs. It also includes a measure of each country's overall arms technology level. We outline our definition of arms technology, our criteria for inclusion in the database, and our data collection process. We also offer guidelines to different uses of the data in empirical analysis, using global arms technology diffusion, its effect on interstate warfare, and its role in shaping the distribution of power within states as cases.

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1 Introduction

Mao Zedong 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 political 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.[1] It follows from this simple proposition that guns, and arms broadly speaking, are fundamental to politics. Arms affect the distribution of power both domestically (where the state is often defined by its monopoly on them) and internationally (where war is said to be a continuation of politics through other means). Political actors, in short, demand arms because "coercion *works*; those who apply substantial force to their fellows get compliance and from that draw the advantages of money, goods, deference" (Tilly 1990, 70. Italics in original).

The quality and technological sophistication of arms are a crucial as their quantity: Scholars have found countless instances where arms technology has changed the nature of warfare, shaped political institutions, and even changed the course of history. Superior arms technology is widely cited as an important reason (and sometimes the main reason) why a few small and medium sized European countries came to dominate the world from the 16$^{\text{th}}$ century to the Cold War.[2] More generally, Van Crefeld's sweeping history of warfare repeatedly states that "war is permeated by technology and governed by it" (Van Creveld 2010, 1 and 311; see also Bas and Coe 2012). Arms technology affects the advantage of a military offense against defense, the so-called "offense/defense balance" (e.g., Snyder 1984, Jervis 1978, and Evera 1984). Arms have also been linked to the emergence and dynamics of international alliances (e.g., Olson and Zeckhauser 1966 and Morrow 1993).

Arms technology also influences domestic politics and institutions. It increase the efficiency of the government's repressive machinery, eases the revolutionary constraint, and reduces the likeli-

[1] *Power* has also been defined as the ability "to prevail in conflict" (Deutsch 1978, 23) or as "the capacity to produced intended effects" (Wrong 2017, 2). According to either understanding, it seems reasonable to view arms technology as a source of power.

[2] Jared Diamond famously attributed European conquest to guns – or arms technology, more broadly – germs and steel (Diamond 1997). Philip Hoffman cited gunpowder technologies – "firearms, artillery, ships armed with guns, and fortifications that could resist bombardment" – as the primary reason "Why Europe Conquered the World" in a book of the same name (Hoffman 2015, p. 7).

hood that rulers grant political rights (e.g., Acemoglu and Robinson 2005).[3] To list a few additional examples, Aristotle famously linked cavalry to oligarchy, infantry to moderate democracy, and galleys to radical democracy (Aristotle 2000[1885], 242). Max Weber (1978[1922], 904-5) argued that "medieval knights made feudal organization inevitable", a development that was enabled by the stirrup (White 1962). Mann (1984) observed that early artillery rendered the medieval castle obsolete, thereby strengthening the Crown against feudal elites in early modern Europe.[4] Andreski (1968, 68-69) identified cheap rifles as the technological requisite for mass conscription, an impetus to increased political rights that was weakened when modern tanks and aircraft made the mass army obsolete (Onorato et al. 2014; Hariri and Wingender 2024).

To facilitate the empirical study of how arms technology affects, and is affected by, warfare, institutions, and politics more broadly, we introduce the Correlates of War (COW) Arms Technology Data Set 1816-2023. The data set contains information on when 29 specific arms technologies were adopted by the law enforcement or the military in different countries.[5] The data are publicly available as a part of the Correlates of War database, and cover all states in the international system 1816-2023, as defined by Correlates of War Project (2017).

The COW Arms Technology Data Set complements existing databases relevant to scholars interested in arms or military capabilities more broadly. It occupies a middle ground between databases containing information on specific weapon systems and databases with more aggregate data on resources that can be devoted to war. Notable among the databases with detailed data on specific weapon systems are the SIPRI Arms Transfers Database and IISS' The Military Balance. While the COW Arms Technology Data Set has less detail than these resources, it extends a century and a half further back in time. It also provides a classifications of arms, which allows researchers to study arms technology without requiring detailed knowledge of specific models.

[3]In formal models, the probability of revolt or regime change often depends on other parameters, including one converting resources invested in repression into actual repression. In Acemoglu et al. (2010), for example, repressive capacity is modeled as the number of soldiers needed to suppress a revolt, i.e., as a form of labor productivity. Although not explicitly mentioned in the paper, progress in arms technology will increase the productivity of soldiers, ultimately increasing the durability of autocracy. Similar theoretical predictions can be found in Grossman (1991, 1995), Grossman and Kim (1996), Skaperdas (2003), and Garfinkel and Skaperdas (2007).

[4]See also Parker (1996, 67f.), and Porter (1994, 31). The historian William McNeill (2013, 95) made the same argument in the context of both the Safavid Empire and Japan.

[5]We refer to the technologies as "arms technologies", not military technologies, as they may be used by semi-militarized law enforcement units within the civilian police, domestic security forces, or gendarmeries.

Notable among the databases with aggregate data on resources that can be devoted to war is the COW National Material Capabilities data set (Singer et al. 1972; Singer 1988, v6.0), which tracks six dimensions of the material basis of countries' power in the international system (population size, urban population, iron and steel production, energy consumption, military personnel, and military expenditure). How effectively such resources can be converted into military power depends, among other things, on arms technology. While these are conceptually distinct, arms technology and material capabilities are of course empirically related: [6] Material capabilities can be directed towards investment in arms technology, but as we show below, they are only moderately correlated and seem to capture distinct aspects of military power.

In the first part of the paper, we outline how we conceptualized arms technology for the purpose of constructing the data set, and how we selected the specific technologies included. We then describe how the data were collected and processed, as well as the coverage and structure of the final data set. Finally, we provide three examples of potential uses of the data set in the social sciences, namely the study of arms diffusion, the study of success in warfare, and the study of domestic repression. These examples provide an opportunity to illustrate different transformations of our data set that could be useful for other purposes.[7] As such, we hope that they will inspire other researchers to use the COW Arms Technology Data Set 1816-2023 in their own research projects.

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, where the term 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 humans use in productive activities. Here, we adopt the narrow hardware-perspective, and

[6] Hariri and Wingender (2024) illustrate that arms technology and certain dimensions of the material capabilities index are distinct by showing that arms technology is negatively associated with military personnel when military expenditure is held constant. This indicates that arms technology is labor saving: along the isocost curve, improved arms technology allows states to reduce the size of armies.

[7] See Hariri and Wingender (2023, 2024) for further applications based on a less comprehensive precursor to the COW Arms Technology Data Set 1816-2023

define arms technology as a piece of equipment explicitly designed to kill, and potentially cause destruction of objects in the process.[8] The definition excludes less tangible social aspects such as military organization and doctrine. We also exclude military hardware primarily designed for non-lethal uses, such as radar systems and armed personnel carriers. Yet lethal and non-lethal technologies are often combined in bundles, which we consider a new arms technology. To give an example, we consider a machine gun mounted on a helicopter to be a technology distinct from both the machine gun and the helicopter.

We define technological progress as new varieties of arms technology that increases the destructive capacity compared to earlier varieties. Progress can take the form of either vertical innovation – the introduction of more destructive versions of existing arms categories – or horizontal innovation – the creation of completely new lines of arms. The invention of the first tank or first military aircraft constituted horizontal innovation, whereas subsequent improvements (later generations of main battle tanks, for example) constitute vertical innovation. We use the distinction between horizontal and vertical innovation when we classify technologies below.

2.1 Which technologies are included in the data, and why

Before we decided on the specific arms technologies to include in the data set, we limited the universe of technologies to be considered as follows. First, we restricted the data to conventional arms. Second, we limited the data to arms used offensively (e.g., by excluding missile defense systems). Third, we disregarded naval technologies as they are irrelevant for landlocked countries. Finally, as the original purpose with collecting the data was to study internal repression, we excluded technologies rarely used internally, such as ballistic missiles. This left us with seven categories of arms: small arms, machine guns, artillery, tanks, fighter aircraft, combat helicopters, and armed unmanned aerial vehicles (UAVs).

Technological progress stems from both ongoing tinkering with existing designs, leading to gradual improvements, and radical new ideas, leading to completely new designs. To make our definition of arms technology operational in a data set covering all countries and more than 200 years of history, we focus on radical innovation. Radical innovation is easy to identify in the

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

horizontal dimension: The first machine gun, the first tank, the first combat aircraft, and so on. Identifying radical vertical innovation is harder as the distinction between radical and gradual is less clear. To be included in our sample of technologies, we required that a vertical innovation led to a substantial 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.[9] 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.

To help us select the technologies to include in the sample, based on our criteria above, we held repeated meetings with experts on military history and military technology.[10] The result of this process is shown in Table 1, which lists the technologies included in the data set.[11] We provide a brief description of each technology in the Appendix.

Some of the arms technologies introduced early in the sample period are distinguished from their predecessors by a single technological innovation, such as a rifled barrel or breech-loading, whereas many of the later ones are bundles of new technologies. Each new generation of the main battle tank in Table 1, for example, differed from its predecessor in many respects – in having more powerful engines, improved armor, guns, transmission mechanisms, more sophisticated aiming and

[9]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.

[10]We are in this context grateful to Ole L. Frantzen (military historian and former director of the The 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). We have also benefited from scholarly works on the history of military technology include Dupuy (1990), O'Connell (1990), Zarzecki (2002), Carman (1955), Manucy (1994), and McNeill (2013).

[11]Some of the experts additionally mentioned smokeless gunpowder and innovations in artillery munitions (shrapnel shells and shells exploding on impact) being important, while warning us that data would be hard to find (something we can confirm). We consequently decided to exclude them. The innovations in artillery shells are in any case closely linked to rifled artillery, a technology included in the data.

detection systems, and so on. Due to international rivalries, and general technological progress, such improvements emerged roughly at the same time in the new models from different arms producers, leading to the widely used classification of tanks, fighters, and combat helicopters into generations. While different classification schemes exist, they only differ in minor details. We rely on the classification scheme in Zarzecki (2002).

It is only natural that technologies become bundled over time. As Liebowitz and Margolis (2012, 84) write: "what passes for two goods at one moment in time may be understood as a single good not many years later."[12] That is to say, even if the differences between two arms technologies were more limited for the earlier varieties in our data and more numerous for the later varieties, this reflects the technological context in which the arms were invented. The percussion lock musket constituted a substantial advantage on the battle field compared to the flint lock even if the actual change to the rifle hardware was limited compared to the difference between two generations of main battle tanks.

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	1st gen. battle tank
Breechloading rifle		Practical breechloading	2nd gen. battle tank
Tubular magazine rifle		Recoil mechanism	3rd gen. battle tank
Box magazine rifle			
Assault rifle			
Fighter aircraft	**Combat helicopters**	**Armed UAVs**	
Early aircraft	1st gen. combat helicopter	Armed UAV	
WWII era fighter	2st gen. combat helicopter		
1st gen. jet fighters			
2st gen. jet fighters			
3st gen. jet fighters			
4st gen. jet fighters			
5st gen. jet fighters			

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

[12] The authors give the example of the automobile, which in its early days consisted of "two separate goods, a running chassis, and a body" and now include also heaters, air conditioners, rust proofing, sound systems and much else as standard equipment (*ibid*).

2.2 Measuring technology at the extensive margin

We collect data on technology adoption at 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 29 arms technologies in our sample. Collecting data on technology adoption at 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 quite informative, however. One reason is that once adoption of a new arm is 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 important. For example, Tsarist Russia adopted the Moisin-Nagant box magazine rifle in 1891, and within five years, two million copies were produced, equipping all Russian soldiers (Grant 2007).[13]

2.3 Measuring aggregate technology levels

The COW Arms Technology Data Set contains information on technology adoption for 29 separate arms technologies, but for some applications, researchers might need to construct an overall measure of a country's level of arms technology. That entails aggregation across diverse technologies, as well as both methodological and practical considerations, which we discuss in this section. How exactly it should be done depends on the research question at hand.

Within the seven categories of arms in the data, the technologies in our sample are strictly hierarchical: a country with automatic machine guns is more advanced within this category than a country with only hand-cranked varieties. 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

[13] See also Boix (2015, 159) for similar examples of swift firearm adoption in 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 to apply 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).

their technology levels in that category.[14]

Aggregating technologies across categories of arms 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 than a new type of small arm depends on the context. The challenge of constructing an aggregate country level-measure of arms technology should not be overstated, however. It is similar to that which confronts scholars measuring, e.g., democracy, government effectiveness, economic freedom, human development, or any other complex concept in the social sciences.[15] One way forward in the context of arms technology is to note that technologies in our data set were invented in different years, which gives rise to a natural ordering. Most countries adopt the new technologies in roughly the same order as they where invented even if the average speed of adoption varies across countries. One can consequently get a reasonable ranking of countries' arms technology by simply looking at the most recently invented technology in their possession.

Rankings based on only a single technology from each country 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 4.2 and 4.3, 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. The index I_{it} gives a correct ordering of arms technology levels if adoption follows the same sequence in all countries. This requirement is not universally met in practice, but it is useful as a first approximation. Moreover, the approximate ordering holds regardless of whether the technologies in our sample are just a subset of a larger universe of arms technologies. For these reasons, we consider the simple index I_{it} a convenient, transparent and informative way to aggregate the arms technologies in the data set to the country level, and we provide the index as a separate variable in the COW Arms Technology Data Set.

The question of sampling leads to the question of whether I_{it}, or other indices one might

[14] A cardinal measure of technology levels within arms categories would require 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).

[15] What is the relative contribution to a country's overall level of democracy from, e.g., freedom of speech relative to freedom of association? The short answer is that they both matter, and they should both count positively towards democracy. As with arms categories, it is difficult *a priori* to argue that one matters more than the other. If scholars find this to be the case in context they study, they can assign weights to reflect the relative importance of the included attributes in their aggregation.

created based on our data, should be viewed as formative or reflective. I_{it} will be reflective if the technologies in our data are regarded as a small sample of the total number of arms technologies that contribute to the overall technology level. In that view, one would consider I_{it} a reflection of an underlying and unobserved technology level. If one considers the technologies in our data set the full population of technologies relevant for the overall technology level, I_{it} should be viewed as a formative index, implying that countries are only technologically advanced to the extent that they have adopted the technologies in our database.[16]

Depending on the research question, one might still 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. In a recent contribution, for example, Hanson and Sigman (2021) argue that state capacity – of which coercive capacity is one dimension – could 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

In this section, we briefly outline our data collection process and describe the sources used. We provide further detail in the documentation accompanying the data set. But let us first be clear about our terminology:

- A technology is "used" by a state in a given year if it was part of the armament in the military or other branches of the government (early prototypes used on an experimental basis do not count, neither do test specimens supplied to governments by producers).
- A technology is "adopted" in the first year in which it is used, according to the definition above.

[16]Recall that in formative index construction, the individual indicators taken together cause or constitute the overarching concept, they are indicators of. In reflective index construction, by contrast, the indicators are seen as the outcome of some unobserved, latent factor. Often, the choice of measurement perspective is straightforward enough because the causal priority between the underlying concept and the indicators is clear. In other cases, however, "the directionality of the relationship is far from obvious" (Fayers et al., 1997, 393). We contend that this is the case here and that coercive capacity and related concepts can meaningfully be quantified using both a formative and reflective measurement model depending on the specific research question at hand.

- A technology is "superseded" if the state currently uses a superior technology within the same category of arms (e.g., we code the flintlock musket as superseded in a country when the country in question adopts the percussion cap musket).

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

For each of the 29 technologies, we aimed 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 our sources were too vague to assess it – we aimed to record the earliest year in which a technology *was* used and the latest year in which it was *not* yet used. When sources were too vague, this approach leaves a gap with no information on technology use, which results in missing observations in the final data set (except when the technology is superseded, in which case we code it as such).

3.1 Sources

The COW Arms Technology Data Set is based on information from about 500 different sources. The full list of sources, broken down by country-technology pairs, can be found in the documentation accompanying the data set.

With the exception of small arms, the diffusion of arms after 1950 is fairly 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 ones 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), and the League of Nations' Armament Yearbook (1924-1940), as well as scholarly works on military history.

3.2 Assumptions

In the more than two centuries of political history covered by the data set, empires have disintegrated, and nation states formed. Obtaining specific information about arms technology around state formation can be challenging. In cases when we have no other information regarding what arms were present at independence, we augment the raw data with a few mild assumptions:

- When states fragment, we assume that the political unit containing the old capital maintained the technology level of the former state. For instance, we consider Czechia to be a continuation of Czechoslovakia, whereas we consider Slovakia to be a new state for which we need to find data.

- When wars of independence are fought successfully, we assume that the new state at independence retained the arms that the pro-independence side used during the war.

- When two or more states are unified, we assume the resulting political unit to have the same technology as the most sophisticated predecessor state.

- 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 them. Specifically, we assume that by 1945 all states possessed box magazine rifles and machine guns, both invented in the 19$^{\text{th}}$ century. If a state possessed any artillery by 1945, we assume that it was recoilless. Finally, we assume that all states gaining independence after 1990 had assault rifles.

3.3 Structure and coverage of the data set

The Arms Technology Dataset is a three-dimensional panel with annual observations for the 29 technologies in all states in the international system, as defined by the Correlates of War Project (2017) State System Membership List, excluding current states with less than half a million inhabitants as of 2016.[17] Among the excluded states, only Brunei and Malta have a military force. We include historical states from the State System Membership List irrespective of population size.

[17] Andorra, Antigua and Barbuda, Bahamas, Brunei, Dominica, Federated States of Micronesia, Grenada, Iceland, Kiribati, Liechtenstein, Marshall Islands, Malta, Monaco, Nauru, Palau, Samoa, San Marino, Sao Tome and Principe, Seychelles, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, Tuvalu, Vanuatu.

We code a state-technology-year triplet in the final data set as "0" if it is "not used" in the terminology introduced above, i.e., if the technology has not yet been adopted or superseded by a superior technology. We code a state-technology-year triplet as "1" if the technology is currently used and not superseded, and "9" if it is superseded. Missing observations are coded as such.[18]

To illustrate how the coding works, consider the French army, which adopted its first effective breech-loading artillery, based on the de Bange system, in 1877. Before that year, we code breech-loading artillery as "0" in France. From 1877 and until 1897, we code "1". From 1898, when the French army adopted the famed recoilless Canon de 75 modéle 1897, we code breech-loading artillery as "9" in France. As one can see from the example, the adoption year can be identified as the first year in which a state-technology-year triplet takes the value 1 (except if it is the first year in which the state is observed).

The three dimensional Arms Technology Data Set consists of 473,309 data points, of which 0.4 percent are missing 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 5,320 state-technology combinations in the data.[19] For 95.5 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 4.5 percent of the observations, 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.

4 Applications

In this section, we provide some simple examples of how the COW Arms Technology Data Set might be used in empirical research. The examples illustrate not only how the data in various transformations can be used in different types of quantitative analysis, but also how the data set can shed light on a diverse range of topics in the social sciences. We focus on international arms

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

[19] In principle there are a total of 5,626 state-technology pairs in the data, but we excluded all pairs in which the technology was invented after the state in the pair ceased to exist. To illustrate, pairs involving tanks in the Kingdom of Two Sicilies are excluded.

diffusion, success in warfare, and internal repression, but the data and methods outlined below can be applied to many other contexts as well.

4.1 The Diffusion of Arms Technology

Patterns of technology diffusion tend to be remarkably consistent across different technologies. After a technology is invented, it is initially adopted by a small group of early users. If and when the technology proves to be effective, its adoption quickly spreads to most other potential users, except for a few late adopters. When the share of technology adopters among potential users is plotted over time, the resulting graph typically takes the shape of an S.[20] Figure 1 shows that the diffusion processes of five selected arms technologies, representing different time periods and categories of arms, have all followed this pattern (we describe the construction of the S-curves in the notes to the figure).

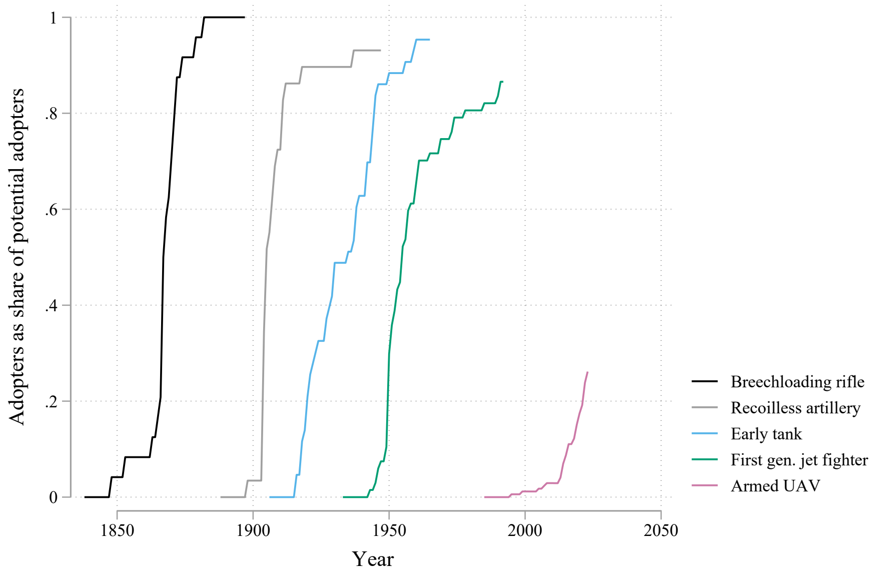
The earliest of the five technologies is the breech-loading rifle, pioneered by Prussia, and only adopted by a few of Prussia's allies before the technology proved to be superior to muzzle loaders in the wars against Denmark (in 1864) and Austria (in 1866). Other countries took notice, and by 1870, only a few states had not yet adopted the new technology. The swift adoption is reflected in the quite steep S-curve for breech-loading rifles in Figure 1.

The S-curves for the other four technologies in the figure look similar, but do not reach an adoption share of "one" in the fifty years-window plotted in the figure (it remains to be seen whether the S-curve for armed UAVs will do so). One reason is surely that rifles, on a per unit basis, are much cheaper than artillery, tanks, and fighter aircraft. Some countries, especially small ones, have for that reason chosen not to adopt them, relying instead on foreign allies or geographical remoteness to provide security.

Another common approach to studying technology diffusion is by the means of adoption lags (see, e.g., the survey in 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. France was, for example, the first country to adopt recoilless artillery in the shape of the Canon de 75 modèle 1897, adopted one year later, in 1898. Germany adopted recoil-less artillery in 1904 (Krupp 7.5 cm model 1903), so the

[20]The economic foundations for why technology diffusion typically is well described by S-curves were famously identified by the economist Zvi Griliches (1957) in the context of hybrid maize.

Figure 1: S-curves, selected technologies

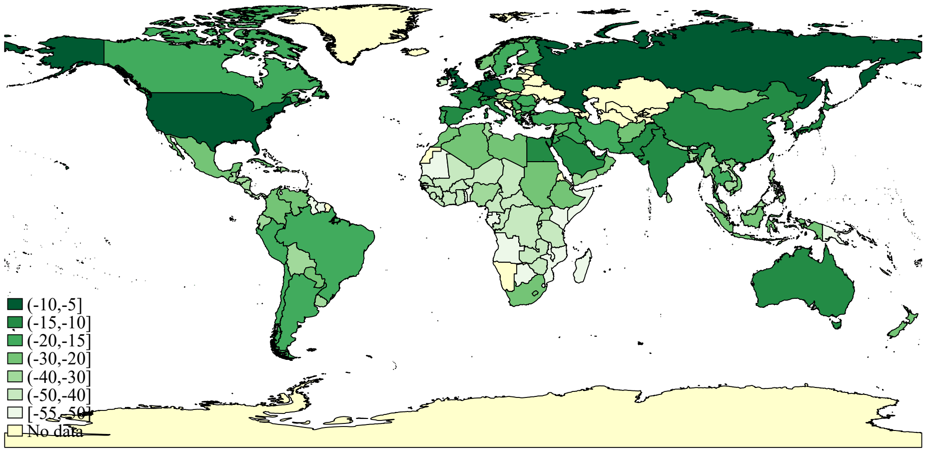


Notes: *This figure reports the share of states that has adopted a given technology in a given year. To avoid noise from states entering or leaving the international system, we balance the sample for each of the technologies in the fifty years after it was first adopted by any state (which is also why we only report adoption in the first fifty years after a technology was first adopted)*

adoption lag for Germany in this case is $1904 - 1898 = 6$ years.

Adoption lags for are unobservable in countries that have not yet adopted a given technology. Researchers must either exclude such instances from the analysis or assume a long adoption lag of a specific length. Here, we provide examples of both approaches along with some practical considerations. The first is Figure 2, which shows a map where countries are shaded according to their average adoption lag over the period 1816-2023. The averages are based on all technologies in the data set, except those widely adopted at the beginning of the sample period (flintlock muskets and field artillery), and those currently in the early stages of diffusion (armed UAVs and fifth generation jet fighters). For individual countries, we omit technologies invented before they joined the international system, resulting in variation the technologies included in the calculation for each country. The sample restrictions means that we observe few, if any, adoption lags in many of the countries that gained independence in the second part of the 20th 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 2 clearly shows the technology frontier in Western Europe plus Russia and the United States.[21].

Figure 2: Average adoption lag by country, 1816-2023



Notes: *Darker shades of green indicate faster average adoption lags across all technologies invented in a year in which the country in question was independent. Adoption lags are truncated at fifty years, including the unobserved adoption lags for countries that have yet to adopt at the end of the sample period. We omit the two technologies invented after the Cold War, namely armed UAVs and fifth generation jet fighters, which are still in the early phases of diffusion, as well as flintlock muskets and field artillery, which were already widespread at the beginning of the sample period. Countries gaining independence at the end of the Cold War or later are excluded as many of them had fairly advanced arms at independence, and therefore had little need to adopt new ones afterwards.*

The map in Figure 2 provides some clues as to how countries vary in the speed with which they adopt new arms technologies. To explore this further, we run the following regression with adoption lags as the outcome variable:

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

where the unit of observation is a technology j observed in country i. We exclude the same technologies as in the map in Figure 2, but we now exclude non-adopters rather than assuming an adoption lag of 50 years. It is not crucial to do so, but the country-technology panel structure in the data provides more observations than in the example with average adoption lags, reducing the sensitivity to outliers, and technology fixed effects and country fixed effects can reduce other forms

[21]The average adoption lags for the frontier countries is between five and ten years, reflecting that the identity of the technology leader has changed over the two centuries, with Prussia/Germany being in the lead in most of the 19$^{\text{th}}$ century, and the United States in most of the 20$^{\text{th}}$

of biases that might arise from omitting non-adopters. The technology fixed effects and the country fixed effects are, respectively, denoted α_j and α_i in the regression. The matrix $\mathbf{X}_{i,j}$ contains a range of potential drivers of technology adoption measured in the year technology j was first adopted anywhere (i.e., in 1898 for recoilless artillery). The technology fixed effects control for unobserved factors intrinsic to the technology, such as unit costs, but they also function as time fixed effects by partialling out factors pertaining to the period when the technology diffused. We convert all the factors contained in $\mathbf{X}_{i,j}$ to dummy variables, to allow us to interpret the coefficients contained in the vector β as the increase in years of technology adoption when a country scores "one" on the dummy in question. As usual, $\varepsilon_{i,j}$ represents the error term.

We include five potential drivers of arms technology adoption in the regression. They are not an exhaustive list, but they are all plausibly related to a country's pattern of arms technological adoption, and they can be measured using publicly available data widely used in empirical research. The first is a dummy for whether a country was at war at any time within the first ten years after invention, as recorded in the Correlates of War list of interstate conflicts (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 at the year of introduction according to the Correlates of War data set of the same name (Singer et al. 1972; Singer 1988, v6.0).[22] 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 2, show that all five country characteristics 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

[22] As mentioned in the introduction, national material capabilities is a composite index of total population, urban population, iron and steel production, energy consumption, military personnel, and military expenditure.

when we include them together in column (6). The one on democracy drops the most and becomes insignificant, most likely because of democracy's positive correlation with GDP per capita and geographical proximity to the technology frontier in Western Europe.[23]

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 do not vary much over time. Most of the 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 drivers of technology adoption. These findings are consistent with the logic of the security dilemma (e.g., Jervis 1978), where countries cannot ignore the risk that neighboring states might use their arms offensively, even if they were originally adopted for defensive (or other domestic) purposes. More broadly, it seems plausible that states are quick to adopt when threatened because they perceive new arms technology to increase the chance of winning wars. Whether superior arms do indeed predict success on the battlefield is the theme of the next subsection.

4.2 Interstate war

To illustrate how researchers can use the COW Arms Technology Dataset to study the outcome of wars, we use interstate wars as the unit of observation, and regress a dummy indicating whether the initiator won the war on a constant and a dummy indicating whether the initiator had more advanced arms than the target.[24] The results allow us to identify any positive correlation between possessing more advanced arms and winning wars, with the coefficients providing approximate probabilities (we leave the thorny question of causality for later analyses).

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 obtain the sample of wars, and information about belligerent parties and outcomes, from the

[23] In analyses of bilateral arms trades, Akerman and Seim (2014) and Comola (2012) find that differences in political regimes are significant 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.

[24] We code draws as 0.5, so they count as a half win. Likewise, we code the dummy for arms technology as 0.5 when the initiator and the target are equally advanced. The estimated coefficients should be interpreted accordingly.

Table 2: Basic correlates with the speed of arms technology adoption

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Warfare	4.67***					2.80***	2.49**
	(1.17)					(0.99)	(0.93)
Adopted by neighbor		7.01***				3.86***	3.20***
		(1.37)				(1.21)	(0.88)
Above median material capabilitie			7.31***			4.68***	1.09
			(1.07)			(0.81)	(1.20)
Above median GDP per capita				6.31***		4.45***	-0.34
				(1.10)		(0.94)	(1.14)
Democracy					4.45***	1.28	-0.19
					(1.49)	(1.19)	(1.47)
Observations	1,064	1,064	1,064	1,064	1,064	1,064	1,038
Technology FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State FE	No	No	No	No	No	No	Yes

Notes: *Table 2 reports regressions based on Equation 1. The units of observation are country-technology pairs. The outcome variable is the adoption lag, i.e., the time from a technology was first introduced until it was adopted by country i. Adopted by neighbor is a dummy for whether a neighboring country adopts the technology within the first ten years of introduction. Warfare is a dummy for whether country i was at war within the first ten years after technology j was invented. GDP per capita and material capabilities are dummies for whether the state scored above the median on these two measures in the year in which a technology was first introduced. Democracy is a dummy for whether a state was democratic in the year the technology was introduced. The data sources are described in the text. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1*

Correlates of War database v4.0 (Sarkees and Wayman 2010), covering all interstate wars in the period 1816-2007.

As a first step, we regress the dummy for winning on just a constant. The result, reported in column (1) of Table 3, shows that the countries that initiated the wars won in 70 percent of cases 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 in the year before the war, measured as described above.[25] The results 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 89 percent of the wars they start, whereas aggressors with inferior arms only win 50 percent.

Advanced arms technology is correlated with other determinants of victory in interstate wars: As documented in Table 2 above, it is substantially and significantly correlated with wealth and material capabilities more broadly. Scholars of war have found both of these factors to shape the likelihood of winning wars. More broadly, the literature has debated the relative merit of wealth, political regimes, and relative material capabilities (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 particularly apt at selecting "winnable" wars (e.g., Reiter and Stam 2010), at fighting the wars they select or have been forced upon them (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).

To illustrate the relevance of arms technology for understanding the outcomes of interstate wars, and that it is distinct from these other determinants of victory, we add dummies indicating whether the initiator had superior material capabilities, and a variable capturing differences in political regime between the initiator and the target.[26] The latter takes the value 1 if a democracy

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

[26] Adding a dummy for a higher GDP level would also have been relevant as a measure of wealth, but GDP data are only available for both the initiator and the target of a war in 67 of the 103 cases. The coefficient on GDP therefore becomes insignificant, but this might be due to the small sample size. Superior arms technology remains statistically significant with $p = 0.03$ even in the smaller sample when we control for GDP.

attacks and autocracy, -1 if an autocracy attacks a democracy, and 0 if the two parties have the same regime, according to the Boix et al. (2013) democracy indicator.

We start in column (3) of Table 3 by adding the dummy for superior material capabilities to our linear probability model. The addition reduces the estimated effect of superior arms technology, but the coefficient of interest remains substantial and statistically significant. Moreover, superior arms technology is associated with a higher estimated probability of winning a war than having superior material capabilities. In columns (4) and (5), we add democracy, respectively with and without controlling for superior material capabilities. Given our specification of the variable, the coefficient on democracy vs. autocracy can be interpreted as the approximate conditional probability that democracies win against autocracies relative to the outcome when the belligerent have the same type of regime. The results show that democracies' added probability of winning when fighting autocracies is about 12-13 percent, but only borderline significant at a ten percent level (the coefficient would be larger and statistically significant if we omitted arms technology from the regression). 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, in part at least, democracies excel at war because of their superior arms technology.

Our analysis of technology diffusion above revealed 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 your opponent is associated with a higher probability of winning.[27]

4.3 Internal repression

In addition to the threat posed by other states, governments face domestic threats. Here, we focus on "the threat from below" – the threat the masses pose to autocratic survival (Svolik 2012). Advanced arms technology makes the repression of collective protest behavior cheaper and easier, and the government's possession of overwhelming military force may silence demands for reform from being voiced at all. That said, both history and current events offer numerous examples of arms being used against protesters – and often with success. In the event-study in Figure 3, we

[27] This also applies to the target, as the dummy is coded as zero when the target adopts faster. Equally fast adoption among the belligerents is coded as 0.5.

Table 3: Arms technology and success in warfare

	(1)	(2)	(3)	(4)	(5)	(6)
Constant	0.70***	0.50***	0.43***	0.53***	0.46***	0.28**
	(0.04)	(0.06)	(0.06)	(0.06)	(0.06)	(0.11)
Superior arms technology		0.39***	0.29***	0.34***	0.22**	0.34***
		(0.10)	(0.10)	(0.10)	(0.10)	(0.11)
Superior material capabilities			0.24***		0.24***	0.20**
			(0.08)		(0.08)	(0.08)
Democracy vs. autocracy				0.12	0.13*	0.13*
				(0.07)	(0.07)	(0.07)
Faster growth in arms tech.						0.26**
						(0.13)
Observations	103	103	103	103	103	101

Notes: *The units of observation are interstate wars from Sarkees and Wayman (2010). The outcome variable is a dummy variable taking the value 1 if the initiator of the war wins. In case of a draw, we set the value to 0.5. Superior arms technology is a dummy for whether the initiator had adopted more military technologies than the target state one year before the onset of the war. The dummy for superior material capabilities is similarly defined. Democracy vs. autocracy is the difference in the dichotomous Boix et al. (2013) democracy indicator between the initiator and the target. Its coefficient can consequently be interpreted as the approximate conditional probability that a democracy beats an autocracy. Growth in arms technology is a dummy for whether the initiator adopts more new arms technologies during the war. In cases with identical technology levels or technology growth, we set the dummies to 0.5. Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$*

show that such success depends on arms technology. Centered in a ten year-window around the onset of popular resistance against autocratic regimes, the figure shows how the probability of democratization depends on the autocrats' access to arms technology. The data on resistance are from the NAVCO database v1.3, which contains information on all resistance movements since 1900. For every year since then, we divide all autocracies in the world into those that, conditional on a range of potential confounders, have more advanced arms technology than the median autocracy, and those that have less.[28]

The results in Figure 3 show that popular protest movements lead to democratization only in countries with less advanced arms technology (represented by the black dots in the figure): One year after the onset of protest, resistance against the regime increases the likelihood of democratization by 15 percentage points for these countries. Among the autocracies not democratizing in the first year, there is an increased likelihood of democratization in the second year. The probability of democratization remains elevated three, four, and five years after the onset of protest activity, reflecting that such movements may last longer than a year before it succeeds.[29] In countries with less advanced arms, however, the effect of popular movements is small and statistically insignificant one year after the onset. Beyond the first year, the point estimates are essentially zero, suggesting that resistance against the regime is not a viable path to democracy in states with advanced arms technology.

We report further evidence consistent with this interpretation in Figure 4, which shows the cumulative number of democratizations in the two subsamples of autocracies. 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). 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

[28] We classify countries as autocracies using the Boix et al. (2013) indicator Both the estimated probabilities and the sample split are conditional on year fixed effects and autocracy-spell fixed effects to eliminate time trends and unobserved heterogeneity across countries and political regimes. We also condition on GDP per capita since economic development is correlated with both technological sophistication (here, of course, in arms) and popular demand for political reform (e.g., Lipset 1959). See Hariri and Wingender (2023) for further discussion.

[29] This is interesting in light of the theoretical model in Acemoglu and Robinson (2000), and empirical findings in Przeworski (2009), which argue that revolutionary threats must be shortlived to achieve regime change.

different during the Cold War.

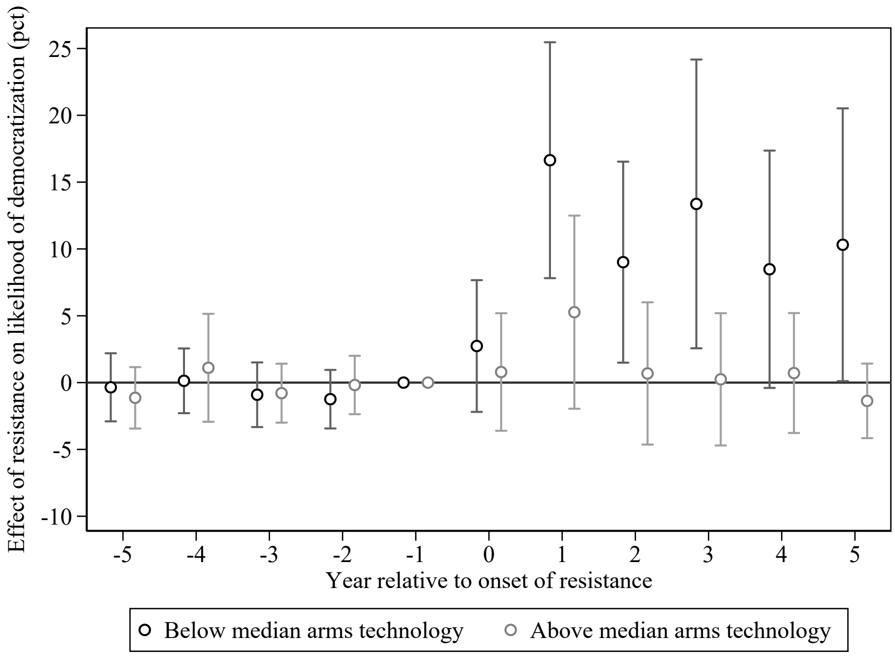
Although the results in Figure 3 and 4 are suggestive, they are still correlations. In Hariri and Wingender (2023), we show that the relationships are likely to be causal.[30] These findings are complementary to the results in Albertus and Menaldo (2012) (and the argument in Bellin 2004), which documents that the size of the military personnel per inhabitant is also negatively associated with transitions to democracy. We leave it for future research to compute domestic and interstate production functions in coercion with the appropriate weighting of capital and labor in each case.

Hariri and Wingender (2023) show, moreover, that advanced arms not only protect authoritarian leaders from pro-democracy movements, they also protect against other internal threats. In fact, advanced arms reduce the likelihood of all forms of regime change – except military coups. One interpretation of the finding that arms technology is uncorrelated with military coups is that while advanced arms technology increases the ability of the military to intervene in politics, it also reduces its inclination to do so (e.g., Powell 2012, Huntington 1991).[31]

[30] The analysis reported in Figure 3 and 4 are similar to analyses reported in the cited paper, but for the data have been updated in the present analyses.

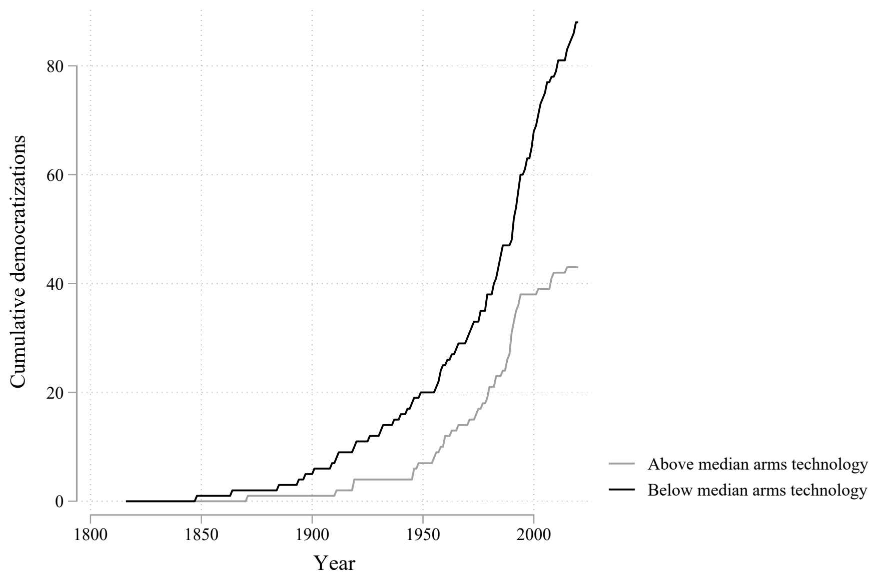
[31] Huntington (1991), for example, made the latter point focusing explicitly on arms technology: "Give them [the military] toys. Provide them with new and fancy tanks, planes, armored cars, artillery [...]. New equipment will make them happy" (Huntington 1991, 252).

Figure 3: Arms technology and popular resistance in autocracies



Notes: *The figures shows the increased probability of democratization around the onset of a resistance movement relative to one year before the onset (the omitted comparison year). The probabilities are estimated using a linear probability model in a panel of autocracies with up to five year leads and lags of a dummy for onset of resistance as explanatory variable. The regression additionally includes autocracy-spell fixed effects, year fixed effects, and log GDP per capita as control variables. We split the sample into countries with above median arms technology, and below median arms technology We calculate medians conditional on the same controls as we include in the regression. Data on resistances are from Chenoweth and Shay (2020). Data on political regimes and democratization are from Boix et al. (2013). The sample period is 1895-2019. The vertical intervals around the point estimates indicate 95 percent confidence bands based on robust standard errors clustered at the country level.*

Figure 4: Democratization and arms technology



Notes: *The figure shows the cumulative the number of democratic transitions in autocracies with fewer/more arms technologies than the median autocracy conditional on GDP/capita. The samples are updated every year such that they include the same number of observations. Data on democratic transitions are from Boix et al. (2013) v4.0, and GDP/capita data are from the Maddison Project Database v2023 (Bolt and van Zanden 2024).*

5 Concluding remarks

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" (quoted in Munck and Snyder 2007).[32] 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 both international relations, comparative politics, and across much of the social sciences.

The COW Arms Technology Data Set 1816-2023 provides data on countries' adoption of 29 groundbreaking arms technologies from 1816 until today. The individual technologies belong to seven separate arms categories, and researchers can at the most granular level study the adoption

[32] 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).

or diffusion of individual technologies over time within or across countries. At a slightly broader level, they can study arms categories or the overall level of arms technological sophistication within and across countries.

The data cover all independent states and more than two centuries of political history. As such they allows students to compare and contrast interstate and domestic political developments across regions, time periods and international polarity structures within an eye to the crucial role that coercion, even to this day, continues to play in politics.

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Appendix: descriptions of the technologies in the data set

Flintlock musket. Invented in the first quarter of the 17^{th} century, possibly in Normandy.

Percussion lock. Improved firing mechanism compared to the flintlock. Dramatically reduced misfire. Patented by Reverend Alexander Forsyth in 1807 (Scotland, Britain). The separate percussion cap was invented *c.* 1814. The percussion lock was not adopted by European armies until the 1830s.

Minié rifle. The key innovation was the conical bullet with expanding base, which made rifling of firearms practical. Loading of rifles was made easier by greased grooves around the bullets' base. The base of the bullet was hollow, so upon firing, the skirts of the bullet expanded to fit the rifling. Before the Minié rifle and its revolutionary bullet, loading of rifles was too slow and cumbersome to be practical for regular soldiers. The accuracy and range of rifles were superior to smoothbore muskets, rifles quickly replaced muskets after the invention of the conical bullet. The Minié rifle was patented by Capt. Claude Etienne Minié of the French army in 1849, and rapidly diffused to other European powers.

Breech-loading rifle. The first practical breech-loading rifle was the Dreyse needle gun, invented in Prussia in the late 1830s. It was nominally accepted in service in Prussia in 1841, but not issued to soldiers until 1848. The breech-loading rifle did not diffuse widely until its superiority was demonstrated in Prussia?s military victories against Denmark and Austria in the 1860s. Breech-loading substantially increased the rate of fire, and breech- loading rifles could be loaded in prone position.

Tubular magazine rifle. The first repeating rifles, which could fire multiple shots before reloading. Several models were developed independently in the United States. The first successful versions include the Spencer and the Henry rifles, which both appeared in 1860.

Box magazine rifle. A more practical repeating rifle. The attachable box magazine facilitated a faster rate of fire. James Paris Lee patented the first box magazine in 1879 in the United States. Similar magazines were developed in the 1880s in Austria (Mannlicher), Norway (Krag-Jorgenson), and Germany (Mauser).

Assault rifle. Selective firing rifle, giving a single soldier the fire power of a machine gun. The most notorious example is the AK-47, invented in the Soviet Union. The AK-47, however, builds on the Sturmgewehr 44, developed in Nazi Germany towards the end of World War II, which we regard as the first assault rifle.

Hand-cranked machine gun. The first machine gun. The firing mechanism is operated by manually turning a handle. The first hand-cranked machine guns were developed independently in Belgium (Montigny mitrailleuse) and in the United States (The Gatling gun and the Agar "coffee mill" machine gun) in the early 1960s.

Automatic machine gun. The automatic firing mechanism increased the rate of fire 3-4 times compared to the hand-cranked versions. The first automatic machine gun was invented by Hiram Maxim in 1884, but did not appear in European armies until around 1890. Includes heavy machine guns, typically mounted on vehicles.

Smoothbore field gun. The first piece of artillery small enough to move around on the battlefield. Charles VIII of France put the first mobile field artillery into action during his 1494 invasion of Italy. Diffused rapidly in Europe and Asia afterwards, but were practically unknown in most of sub-Saharan Africa until the continent was colonized in the late 19^{th} century.

Rifled artillery. Rifling improved range and accuracy, and made it possible to use shells that exploded on impact. The first notable appearance were the guns used in the British bombardment of Sebastopol in the Crimean war. Rifled field guns appeared in the late 1850s in Britain, France and Prussia, and became widespread in the rest of Europe in the 1860s.

Steel tubes (artillery). Steel tubes greatly improved the durability of artillery, making larger loads possible. The first steel cannons were brought to the market by the German firm Krupp in 1864.

Breech-loading artillery. Breech loading made loading faster and more practical. Breech-loading cannons have been around for centuries, but were generally not very effective due to two problems. An opening in the breech made artillery less durable and reduced the loads that could be fired. Moreover, openings in the breech could not be sealed properly, which reduced muzzle velocity for a given load. Two separate technologies solved these problems. One was the Krupp sliding breech gun presented at the 1873 World's Fair, and sold to numerous countries afterwards. The other was the interrupted screw, invented by the Frenchman Charles Ragon de Bange in 1877.

Recoil mechanism for artillery. Hydraulic mechanism for absorbing recoil. Allowed for a substantially faster rate of fire because the artillery no longer had to be re-aimed before each shot. There were some early attempts to add recoil absorption to artillery in the 1880s and 1890s, but the first practical artillery piece with effective recoil absorption was the French Canone Modele 75 from 1897.

Early tank. Developed during World War I. The first tank to appear on battlefields was the British Mark I in 1916, followed by the French FT 17 in 1917, and the German A7V in 1918.

WWII era tank. Tanks did evolve somewhat in the interwar period, but the Soviet T-34 medium tank marked a new era of tank warfare. The T-34, introduced in 1940, featured heavy sloped armor, a high-velocity gun and a powerful engine. It outclassed the German tanks at the East front, and prompted both Germany and the major powers on the allied side to develop comparable tanks. We code postwar light tanks in this category as well, as they have similar effectiveness as measured by the SIPRI TIV.

First generation main battle tank. Had larger guns, heavier armor and wider tracks than their WWII predecessors. The first of this class of tank was the Soviet T-54/55, which appeared in 1948.

Second generation main battle tank. Had more powerful engines, improved armor, guns, transmission mechanisms, and sophisticated aiming and detection systems. The first tank of the second generation was the American M-60, which appeared in 1960.

Third generation main battle tank. Improved armor based on composite materials rather than steel, and advanced fire control systems. The first third generation main battle tank was the West German Leopard 2, which appeared in 1980.

Early attack aircraft. The first air attacks were conducted by pilots in small civilian planes lobbing grenades or firing pistols at enemies. Purpose-built attack aircraft arrived shortly after, during World War I. We code early attack aircraft as adopted if a country has either aircraft with onboard machine guns, or heavy bombers.

WWII era attack aircraft. A new generation of attack aircraft appeared in the 1930s. Contrary to their predecessors, they were monoplanes, had metal frames, retracting landing gear, and V-12 liquid-cooled engines. These innovations improved speed and range dramatically, and allowed them to carry heavy weaponry. The first aircraft to fulfill these requirements were the Soviet Polikarpov I-16, introduced in 1934. Other notable models include the Messerschmitt Bf109 (Germany, 1937) and the Spitfire (U.K., 1938).

First generation jet fighters. First attack aircraft to have jet engines. The first jet fighters to be introduced were the German Messerschmitt Me 262 and the British Gloster Meteor, both introduced in 1944. Note that Zarzecki (2002) does not include these early models in his classification scheme.

Second generation jet fighter. Able to maintain supersonic speeds. Improved ground attack capabilities, and air-to-air missiles. The American F-100 was the first to be introduced, in 1954.

Third generation jet fighter. Better engines, radars, and navigation systems. The first fighters to feature variable geometry airfoils. The Soviet MiG-21, introduced in 1960, was the first of its generation.

Fourth generation jet fighter. Increased maneuverability, improved radars, precision-guided munitions, and improved navigation. The American F-14, introduced in 1972, was the first of its generation.

Fifth generation jet fighter. Small radar cross-sections (stealth), improved sensors, and supercruise capabiloties, among other things. The Lockheed Martin F-22 Raptor, introduced in 2005, was the first of its generation

First generation attack helicopter. The first dedicated attack helicopters. The first was the American AH-1, introduced in 1967.

Second generation attack helicopter. More powerful engines and weapon systems. Night/all-weather fighting capabilities. The first was the American AH-64, introduced in 1986.

Armed unmanned aerial vehicles (UAVs). Drones with attack capabilities. The first was the General Atomics MQ-1 Predator, introduced in 1995.