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Poor Man's Atomic Bomb? Exploring the Relationship between "Weapons of Mass Destruction"

Michael C. Horowitz[1] and Neil Narang[2]

Abstract

The causes and consequences of nuclear proliferation have received a great deal of academic attention. However, nuclear weapons are rarely discussed in isolation in policy circles. Instead, nuclear weapons are relevant as part of a category of weapons of mass destruction (WMDs) that includes chemical and biological weapons (CBWs). Are the factors that drive CBWs proliferation similar to those that drive nuclear proliferation? What is the relationship between these weapons types? In this article, we explore whether nuclear weapons and CBWs serve as complements or substitutes. Using newly collected data on both CBWs pursuit and possession over time, we find that nuclear, biological, and chemical weapons generally function as complements at the pursuit stage. In addition, countries that acquire nuclear weapons become less interested in pursuing other types of WMDs and are even willing to give them up in some cases.

Keywords

weapons of mass destruction, chemical weapons proliferation, biological weapons proliferation, nonproliferation, Poor Man's Atomic Bomb, Chemical Weapons Convention (CWC), Biological Weapons Convention (BWC)

[1] Department of Political Science, University of Pennsylvania, Philadelphia, PA, USA
[2] Department of Political Science, University of California, Santa Barbara, CA, USA

Corresponding Author:
Neil Narang, Department of Political Science, University of California, 9420, Ellison Hall 3710, Santa Barbara, CA 93106, USA.
Email: narangn@gmail.com

What motivates countries to pursue weapons of mass destruction (WMDs)?[1] Despite a wave of research over the last several years on the spread of nuclear weapons and the consequences for international security, the spread of chemical and biological weapons (CBWs) remains relatively underexplored. In some ways, this makes sense—the West's concern with Iran's WMD development program is not driven by Iran's chemical or biological weapons programs. Instead, it is Iran's pursuit of nuclear weapons that propels international concern about the Iranian regime. On the other hand, policy makers worried a great deal about Saddam Hussein's CBWs arsenal before the Gulf War—especially after evidence surfaced of Saddam's usage of chemical weapons against the Kurdish population in Northern Iraq. As the "poor man's atomic bomb," CBWs seem to be viewed by many countries as the best chance they have, short of nuclear weapons, at developing deadly weapons to protect themselves against their neighbors—or increase their ability to threaten them.

In this article, we present the first rigorous tests measuring the spread of CBWs, focusing on both the pursuit of these systems and their implications. More important, we focus on the interaction between biological, chemical, and nuclear weapons proliferation, evaluating the extent to which the pursuit or possession of one type of WMD influences the pursuit of another type of WMD.

Do policy makers and military leaders treat nuclear, CBWs as substitutes or complements in their overall weapons arsenal? What is the actual relationship between nuclear, biological, and chemical weapons possession empirically? Does possessing a nuclear weapons program or capability increase or decrease the probability that a state will pursue biological or chemical weapons and vice versa? Finally, are the same factors known to be correlated with nuclear weapons proliferation also correlated with CBWs proliferation?

The answers to these questions are important for academics and policy makers. For example, if the evidence suggests that leaders treat nuclear, biological, and chemical weapons capabilities as substitutes in their strategic arsenal (perhaps because each one is perceived to increase national security in a similar way), then analysts should adjust their assessments of proliferation risk downward for one capability conditional on observing another. Conversely, if evidence suggests that leaders treat these weapons technologies as complements, then analysts should adjust their assessments of proliferation risk upward for any one technology upon observing another. Finally, if the evidence suggests that leaders treat the three weapons capabilities as substitutes, then efforts to create a more robust nuclear nonproliferation regime could have the inadvertent consequence of increasing demand for CBWs capabilities, thus shifting proliferation risk.

Our results demonstrate three critical facets of the relationship between nuclear, biological, and chemical weapons proliferation. First, we find that many of the same security and economic factors that drive nuclear weapons proliferation also influence CBWs proliferation. Second, while we lack causal evidence, our statistical models support our argument that nuclear, biological, and chemical weapons generally function as complements at the pursuit stage. That is, countries that seek one of these weapons generally

seek all three simultaneously. Third, there is some tentative evidence that WMDs do function as substitutes in one important fashion; once countries acquire nuclear weapons, they become less interested in initiating pursuit of other types of WMDs and they are more likely to abandon other types of WMDs. This key finding provides an empirical basis for the notion that CBWs function as a "poor man's nuclear bomb," since possession of nuclear weapons appears to be systematically associated with a reduction in the demand for less powerful CBWs.

In what follows, we briefly describe the existing literature on nuclear weapons proliferation and the use of CBWs in order to derive a series of hypotheses about the underlying causes of CBWs proliferation, and the relationship between the pursuit of these weapons and nuclear weapons possession. We then describe a new data gathering effort to measure the extent of CBW proliferation. In the following section, we use these data to model the spread of WMDs with a series of event history models. Finally, we conclude with a brief discussion of the results and their policy implications.

Literature Review

Policy makers and analysts often use the term weapons of mass destruction to distinguish a broad class of nonconventional weapons technologies including chemical, biological, and radiological weapons. Perhaps not surprisingly, the increasing scope and application of the term has generated a considerable amount of debate from members of the military and technical communities, who typically differentiate the technologies by their strategic purpose and destructive potential. Indeed, the popular use of the term may obscure differences between nuclear, CBWs by implying a relationship that may or may not actually exist.

As referenced in the Introduction, nearly all of the scholarly knowledge accumulated over the last decade concerning the proliferation of WMDs have focused exclusively on nuclear weapons. Research by Singh and Way (2004) and Jo and Gartzke (2007) demonstrates the way several factors influence whether countries are likely to pursue nuclear weapons and whether they are likely to succeed in acquiring nuclear weapons. The articles come to very similar conclusions: both find that countries facing dangerous security environments are more likely to build nuclear weapons, and both show that underlying economic and industrial capacity play a critical role in predicting which countries will pursue nuclear weapons. Gartzke shows how these same risk factors can influence nuclear force structure as well. More recent research—including articles in this special issue—explore the impact of sensitive nuclear assistance (Kaplow and Brown), security assurances (Bleek and Lorber; Matthew Kroenig), and nuclear arsenal size (Matthew Kroenig) on the likelihood of nuclear weapons proliferation.

Should we expect the factors that drive nuclear weapons proliferation to also influence CBW proliferation? The policy-related scholarship on CBWs provides little answer, emphasizing instead their importance in the post–cold war era (Carus 1991; Smith 2000; Einhorn and Flournoy 2003). Meanwhile there has been limited

academic literature on CBW-related issues, and what has been published focuses overwhelmingly on CBW proliferation from a deterrence perspective. For example, Sagan's work on calculated ambiguity examined whether or not the United States should respond with overwhelming force if hit with a chemical or biological weapons attack (Sagan 2000; Martin and Sagan 2001). While instructive, its emphasis is different from identifying the underlying factors that lead to CBW proliferation, so that analysts can identify proliferation risk before it materializes.

Another set of literature on CBW proliferation focuses on the arms control agreements, both explicit and implicit, designed to restrain their use. For example, Legro (1995) argues that while both Britain and Germany possessed offensive CW (Chemical Weapons) capabilities in World War II, neither employed them in conflict because of a combination of institutional constraints based on norms, realist considerations based on a fear of retaliation, and organizational culture-related factors that combined to decrease the preparedness of all parties for chemical warfare (Legro 1995, 221-25).

The issue of WMD usage may seem unrelated to that of WMD proliferation. Yet, the question of whether or not the same variables that drive nuclear proliferation also influence demand for CBWs depends, in large part, on the assumptions made concerning the destructive power of CBWs and how countries can use them for leverage in international politics. In some ways, the popular usage of the term weapons of mass destruction itself suggests an increasingly common answer. Whether or not it is accurate, the frequent grouping of these three weapons in policy discussions suggests that similar factors might drive their proliferation and that a common policy response could be crafted.

Theory

In this article, we develop a theory and test arguments focused on whether it is appropriate to think about different WMDs as complements or substitutes. The crux is whether countries consider CBWs for the same purposes where they would otherwise consider using nuclear weapons. By complements, we mean that the three weapons technologies might *tend* to be "consumed" together on average, not that they are necessarily perfect complements in that they *have* to be consumed together. This would be the case if countries viewed CBWs as filling different roles in their overall arsenals in ways that bolster their overall capabilities. By substitutes, we mean that the three technologies might potentially replace each on average, not that they are necessarily perfect substitutes in that states will always trade-off one weapon for the other. For example, if countries mostly pursue CBWs when they are simply unable to acquire nuclear weapons, they could more reasonably be considered substitutes. If countries viewed CBWs as equally powerful to nuclear weapons in terms of the ability to deter attack or coerce adversaries it would also be evidence of substitution. Alternatively, the demand for each type may be entirely uncorrelated

if, for example, the function of each weapon and the conditions under which they are likely to be used are completely orthogonal.

As a starting point, consider the theoretical destructive power of CBWs. Chemical weapons began as battlefield weapons employed by the Germans in World War I, a development quickly mimicked by the Entente Powers. Although the use of chemical weapons in World War I was not decisive, all sides eventually developed chemical weapons prior to and during World War II, though they were never officially employed during the conflict. Yet, of the three—biological, chemical, and nuclear weapons—chemical weapons have certainly been the most utilized type historically. As the Egyptian use against Yemen, the Japanese use against China, and the Italian use against Ethiopia demonstrate, one-sided uses of chemical weapons have been especially effective in warfare (Stockholm International Peace Research Institute 1973, 87).

Especially in cases of asymmetric capabilities, when a country cannot respond in kind with chemical weapons and/or lacks the proper defenses, chemical weapons attacks have proved somewhat effective. In particular, Iraq's use of chemical weapons against Iran highlights the dangers of chemical warfare. While only 45,000 of the estimated 1 million deaths in the Iraq–Iran war were due to Iraq's use of nerve and blood agents, they induced widespread fear in Iranian lines. By combining chemical attacks, which disoriented Iranian forces and created panic, with follow-up conventional assaults, Iraq was able to triumph over an adversary that might have otherwise emerged victorious (Mauroni 2003, 152-53). Additionally, as the Iraqi use against the Kurds demonstrates, chemical weapons have potential uses to suppress internal violence as well.

Biological weapons have been used much less than chemical weapons on the battlefield, although they have been deployed several times over the last century. The infamous Japanese unit 731 conducted biological weapons experiments and utilized biological weapons against the Chinese population (Stockholm International Peace Research Institute 1973). Allegations also persist that the Rhodesian government developed and utilized biological weapons during the war that led to the establishment of Zimbabwe (Martinez 2002).

CBWs may also have utility for the purposes of international bargaining—especially at lower levels of hostility—compared to nuclear weapons because they are perceived as more usable. Despite their perception as inhumane, chemical weapons have been used in warfare several times in the last fifty years. Although biological weapons have not been used often, international perceptions of their importance have always been high. The United States maintained an active offensive BW (Biological Weapons) research program until the 1970s. Revelations about Iraq's biological weapons program after 1991 and about the former Soviet BW program exposed the possibility of biological warfare to a broad international audience (Moodie 2001). Combined with widespread policy analysis of the risks of biological warfare, the credibility of biological weapons threats may be relatively high compared to nuclear weapons due to perceptions that nations are unlikely to use nuclear weapons.

This supposition is plausible given that the blast radius, the area affected by the delivery of a single weapon, and the number of people likely killed would be much higher for an average nuclear attack in comparison to an average biological or chemical attack (Cordesman 2001). If CBWs are perceived as more usable than nuclear weapons and fulfill somewhat different missions, they might complement each other in a national military arsenal.

Additionally, most countries do not view CBWs as destructive enough to actually substitute for nuclear weapons. To this end, Zelicoff (2001) argues that the magnitude of destruction possible from chemical weapons means they are not WMDs.[2] The historical record provides some support for this view. While the Germans achieved an important tactical breakthrough at the battle at Second Ypres in 1915, once both sides in World War I developed their own chemical arsenals and defenses, the weapons ceased to be decisive. Also, weather conditions such as sunlight and wind can heavily influence the relative effectiveness of chemical weapons (Hammond 1999, 65). This makes them relatively unreliable in many cases. The difficulty of mating chemical weapons onto missiles also complicates perceptions of their relative effectiveness (Karp 1996). Even with the United States in World War I, when 26.8 percent of US casualties were due to chemical weapons, only 2 percent of those casualties died (Spiers 1994, 4). Attempted uses of chemical weapons in the post–cold war era may also illustrate the difficulties involved in their delivery. When Aum Shinrikyo distributed sarin gas in the Japanese subway system in 1995, thousands were sent to the hospital but only twelve died (Tucker 2001).

Similarly, biological weapons, while offering the possibility for massive destruction, also face a multiplicity of technical complications that potentially reduces their relative utility.[3] First, biological agents are unlikely to survive for a long time in the open atmosphere, meaning they have to be delivered rapidly. Second, changing weather conditions could undermine the effectiveness of a BW attack (Panofsky 1998). Third, biological weapons would either have to be directly placed in a position to cause destruction, such as the poisoning of a water supply, or sprayed in the air above a city. This is harder to do than many realize and reduces the probability of a successful BW attack (Karp 1996). Finally, if proper warning and containment occur, passive defense measures can substantially cut into the impact of a BW attack (Office of Technology Assessment 1993, 52). For these reasons, it is perhaps not surprising that the empirical record is mixed on the perceived effectiveness of biological weapons. For instance, the United States abandoned its offensive biological weapons program in the early 1970s, believing biological weapons did not provide a relative edge in combat.

CBWs also have limited utility in counterforce usages against infrastructure and strategic targets. Since they are predominantly useful for generating casualties, they cannot substitute for the destructive counterforce power of nuclear weapons. Together, the substantial technical limitations of CBWs and the distinct patterns in their historical usage on the battlefield (smaller scale and often domestic threats) suggest that to some degree the three weapons may be treated as complements in

states' overall weapons portfolio. If this supposition is accurate, the popular usage of the term WMD may obscure more than it clarifies, especially if it leads to a single WMD counterproliferation policy under the assumption that the demand for each type is driven by the same factors.

Hypothesis 1: Nuclear weapons and CBWs should function as complements: countries with a nuclear weapon will be equally—if not more—likely to pursue CBWs (simultaneously) compared to countries without nuclear weapons

However, despite these limitations, there are reasons to think that countries might consider CBWs as potential substitutes for nuclear weapons as well. For example, while it is true that mustard and blood gases are unlikely to cause mass destruction, more modern nerve gases such as sarin or VX, if disseminated on a wide scale, could actually lead to massive casualties (Stockholm International Peace Research Institute 1973, 84-85). Most importantly for the purposes of this article, it is the international *perception* that chemical weapons are effective, not their actual effectiveness, that determines whether countries and nonstate actors seek to acquire them.

Even though weather and technology-related factors may make effective utilization difficult, they are generally perceived internationally as a powerful weapon that can be a difference maker in times of conflict. And for this reason, many analysts have characterized them as the "poor man's atomic bomb," implying that they can satisfy the same underlying demand for states when nuclear weapons acquisition is infeasible (Burck and Flowerree 1991, XI; Hammond 1999, X-XI; Mauroni 2003, XIII).

Similarly, although biological weapons are difficult to deliver, Steinbrunner (1997–1998) argues the consequences of their use are almost unlimited. Given the new possibilities for genetic manipulations made possible by modern science, biological weapons could threaten the future of human civilization. The Office of Technology Assessment (1993, 52) while cautioning that the probability of effective use is much lower than for nuclear weapons, concluded in 1993 that, pound for pound, biological weapons might be more devastating for human populations than nuclear weapons. Even though the probability of effective use is low, the enormous magnitude may make biological weapons a credible threat. US policy makers certainly take the threat seriously. In an oft-repeated statement on the risk of biological warfare, the Office of Technology Assessment also noted that the distribution of 100 kg of anthrax in the air over a city could kill up to three million people (British Broadcasting Company 1998). As with chemical weapons, while defensive measures can mitigate the terminal impact, in cases of asymmetric capabilities, the threat to use biological weapons could be especially credible because the possibility of mass disease in the homeland or among troops deployed abroad is so frightening (Mauroni 2003, XV).

Similar to chemical weapons, the fear of the impact of biological weapons even more than a rational cost–benefit analysis may make them equally valuable as a

deterrent in international politics. That is, for whatever their technical limitations, so long as states perceive that CBW possession will enhance their capabilities in a crisis, acquiring them may satisfy the same underlying demand by states when nuclear weapons acquisition is infeasible.

Critical here, however, is the role of nuclear weapons. That CBWs may serve as substitutes for a country if they cannot acquire nuclear weapons suggests that nuclear weapons themselves might serve as a substitute for CBWs. Nuclear weapons are arguably one of the most powerful and important weapons ever developed (Brodie et al. 1946; Jervis 1989). The massive destructive power of nuclear weapons and the perception that their acquisition will bolster the coercive capabilities of a state (whether or not that is actually true) could lead states to decide that, if they have nuclear weapons, they do not need other types of WMDs. In this way, nuclear weapons and CBWs would also be substitutes. We test this supposition in the form of the following hypothesis:

> **Hypothesis 2:** Nuclear weapons and CBWs should function as substitutes: countries with nuclear weapons will be less likely to pursue CBWs compared to countries without nuclear weapons ceteris paribus.

A final possibility is that the proliferation of different types of WMDs is unrelated. If CBW serve distinct strategic functions compared to nuclear weapons (i.e., they are deployed and used in different contingencies and/or in response to different threats), perhaps other factors might govern their proliferation, thus causing them to behave less like functional substitutes or complements.

Research Design

In economics, the typical measurement used to determine if two or more goods behave as substitutes or complements is the cross elasticity of demand, which is measured as the percentage change in demand for the first good that occurs in response to a percentage change in the price of a second. The more negative the cross elasticity of demand, the more the two products behave as complements, while the more positive the cross elasticity of demand, the more the two products behave as substitutes. Unfortunately, it is impossible for us to gather accurate price and quantity data for various WMDs over time in order to estimate how fluctuations in the ''price'' one type of WMD effects the pursuit (or quantity demanded) of the other.

As an alternative to this ideal approach, we estimate the impact of pursuing and possessing any one WMD type on the risk a state will eventually pursue another type, holding that state's underlying ''willingness'' to pursue a WMD (demand) constant. In other words, at any given level of demand for a WMD—which we approximate using a vector of indicators that previous research has shown to be associated with states' willingness to pursue a WMD—we estimate the *independent*

effect of acquiring one weapon technology on the demand for another (indicated by pursuit of that weapon). In this way, our analysis is similar to asking whether a consumer with sufficient enough demand to enter the market for a caffeinated beverage will be less likely to pursue coffee if she is suddenly given tea—where, in our case, the vector of control variables approximates the propensity for a state to enter the market for a WMD in the first place.

The dependent variable for all of our models is the initiation of nuclear, biological, or chemical weapons pursuit. For data on countries that pursued or possessed nuclear weapons in any year, we used data from a special issue of the *Journal of Conflict Resolution* that focused on causes and consequences of nuclear proliferation (Gartzke and Kroenig 2009). These data represent a consensus of several authors working in the field, and thus they ensure comparability of our results to previous research and the articles in this special issue.[4]

Gathering data on countries that pursued and possessed CBWs presented a larger challenge. There is no previously established data on CBW proliferation, excluding initial data created by Horowitz (2004). The Horowitz data relied on several different government and nongovernmental compendiums that tracked WMD proliferation across time (these include Stockholm International Peace Research Institute 1973; Burck and Flowerree 1991; Center for Nonproliferation Studies 2012; Kerr 2008).[5]

We made several improvements to the Horowitz data. First, we added sources to increase its reliability and fill in gaps.[6] In all cases, US government data, which we considered more reliable since it presumably reflects intelligence sources, were privileged when secondary sources disagreed with US government data. Unfortunately, US government data are only available for the post–cold war period. For the cold war period, we relied on secondary sources recommended by experts in the field, coding cases of CBW pursuit to reflect what the balance of those sources believed was true at a given point in time.

Second, one problem with many of the existing CBW data sources is that they either focus on a single year or only go back to a relatively recent point in time. It is extremely difficult to find sources that cover the entirety of a period when a country may have been pursuing biological or chemical weapons. Therefore, we had to conduct additional research to resolve discrepancies. In the Online Appendix, we detail robustness checks that demonstrate the results below are not simply the artifact of particular coding decisions.[7]

Based on this data collection strategy, we created a ''chemical weapons pursuit'' and a ''biological weapons pursuit'' variable for countries pursuing those weapons in a given year, as well as a possession variable for countries that possessed them in a particular year. Chemical weapons pursuit is 1 if a country pursued chemical weapons in a given year and 0 otherwise. Chemical weapons possession is 1 if a country pursued chemical weapons in a given year and 0 otherwise. We created identical variables for biological weapons proliferation as well. Tables 1 and 2 show our current coding of the pursuit and possession of biological (Table 1) and chemical (Table 2) weapons from 1945 to 2000.[8]

Table 1. Pursuit and Possession of Biological Weapons, 1945–2000.

Country	Years in *pursuit* of biological weapons	Years in *possession* of biological weapons
Algeria	1999–2000	
Bulgaria	1988–1993	
China	1950–1961	1962–2000
Cuba	1988–1993	
Egypt	1945–1971	1972–2000
France		1945–1973
Germany	1945	
Iraq	1974–1986,1992–2000	1987–1991
Iran	1981–2000	
Japan		1945
Laos	1988–1993	
Libya	1988–2000	
North Korea	1965–1987	1988–2000
Russia		1945–2000
South Africa	1945–1975	1976–1993
Syria	1990–2000	
Taiwan	1975–1993	
United Kingdom		1945–1956
United States		1940–1973
Vietnam	1988–1993	
Zimbabwe	1975	1976–1980

In the following analyses, we are sensitive to the concern that including too many covariates risks distorting the analysis and makes it difficult to observe the actual effect of the independent variables of interest. We therefore estimate two sets of models. The first set includes only the WMD variables. This allows us to see a first cut of the relationship between biological, chemical, and nuclear weapons proliferation and demonstrates that the subsequent results are not artifacts of including controls (Achen 2005).[9]

We also want to control for a small set of other factors that might influence the relative probability that a country pursues a particular type of WMD. Our goal here is to make the treatment group—those possessing a particular WMD—look as similar as possible to the nontreated group in every way except for variation in the treatment. Failing to control for these differences in our model would be akin comparing an "untreated" Iceland (which never possess nuclear weapons) with a "treated" United States (which possess nuclear weapons) and attributing any differences in biological weapons pursuit (one of our dependent variables) to differences in nuclear weapons possession. Failing to control for these confounds could thus bias our estimate of the causal effect of nuclear weapons possession on biological or chemical weapons pursuit.

Table 2. Pursuit and Possession of Chemical Weapons, 1945–2000.

Country	Years in *pursuit* of chemical weapons	Years in *possession* of chemical weapons
Afghanistan	1982–1994	
Algeria	1999–2000	
Angola	1984–1993	
Argentina	1971–1993	
Australia	1945–1973	
Brazil	1988–1993	
Burma	1988–2000	
Canada		1945–1946
Chad	1988–1993	
Chile	1988–1993	
China		1945–2000
Czechoslovakia		1945
East Germany	1980–1982	1983–1989
Egypt	1945–1962	1963–2000
Ethiopia	1980–1993	
France		1945–1993
Germany		1945
Greece		1945
Hungary		1945
India		1947–2000
Iraq	1971–1979	1980–2000
Iran	1983	1984–2000
Israel	1952–1955	1956–2000
Japan		1945
Kazakhstan		1991–2000
Laos	1988–1993	
Libya	1976–1980	1981–2000
Mozambique	1988–1993	
North Korea	1965–1987	1988–2000
Pakistan	1982–1986	1987–2000
Peru	1988–1993	
Philippines	1988–1993	
Poland		1945
Russia		1945–2000
Saudi Arabia	1988–1989	1990–2000
Somalia	1988–2000	
South Africa		1945–1993
South Korea	1967–1988	1988–2000
Spain		1945
Sudan	1990–2000	
Sweden	1945–1973	
Syria	1971–1972	1973–2000

(continued)

Table 2. (continued)

Country	Years in *pursuit* of chemical weapons	Years in *possession* of chemical weapons
Taiwan	1970–1982	1983–2000
Thailand	1988–1993	
United Kingdom		1945–1957
United States		1945–2000
Vietnam	1975–1989	1990–2000
Yugoslavia	1958–1968	1969–2000
Zimbabwe	1975	1976–1980

While prior research has directly controlled for the way the security environment might influence whether a country pursues WMDs, variables measuring MID (Militarized Interstate Dispute) participation, whether a country is in an enduring rivalry, or whether a country faces a nuclear threat might be intervening factors in the causal pathway between our independent and dependent variables. Indeed, prior research suggests that acquiring nuclear, chemical, or biological weapons can itself generate crisis outcomes, meaning these factors are posttreatment consequences of our independent variables, and not strictly a pretreatment source of omitted variable bias. Thus, including these variables as controls could lead to posttreatment bias (Gleman and Hill 2006; Angrist and Pischke 2008), which could underestimate the total effect of a particular WMD since we are controlling for the pathway through which one effects the other. However, we still want to control for the security environment somehow. Therefore, following Way and Weeks (2012), we control for the security environment using the number of shared land borders (or less than twenty-five miles of separation by sea) a state shares with other states (Stinnett et al. 2002). We also control for whether or not a country has a nuclear-armed ally, since that potentially influences a whole range of national choices about weapons acquisition (Jo and Gartzke 2007; Singh and Way 2004).[10] As described below, the results are consistent even when we include traditional security controls.

We also include two economic variables designed to control for the capacity of a country to build different WMDs. Gross domestic product (*GDP*) per capita and *GDP* per capita *squared* measure the relative wealth of a given country in a particular year. To test the way international treaties might influence national decision making, we generated a *WMD Treaty* variable. The content of this variable depends on the dependent variable. For CW pursuit, the variable is 1 if a country ratified the Chemical Weapons Convention (CWC) and 0 otherwise. For BW pursuit the relevant treaty is the Biological Weapons Convention (BWC), and for nuclear weapons pursuit it is the Nuclear Non-Proliferation Treaty. We also generated a *WMD Treaty System* variable that measures the proportion of countries around the world that have ratified the relevant treaty.[11]

Finally, given that countries have utilized CBWs in the past to quell domestic protests and defeat violent opponents to the regime, we control for *Domestic Unrest*. The variable comes from the Banks data (Banks 2005; Jo and Gartzke 2007). It measures whether a country has faced riots, strikes, or antigovernment demonstrations, indexed by the size of the population.

In the Online Appendix (Tables S1 and S2), we demonstrate that our results are robust even when including the full consensus demand function used by prior research to estimate the probability that a country pursues nuclear weapons. These additional variables are drawn from Singh and Way (2004) and Jo and Gartzke (2007). They include prior MID participation, involvement in an enduring rivalry, whether a country has a rival with nuclear weapons, additional measures of economic capacity, and measures of regime type. Controlling for whether or not a country is a democracy, in particular, allows us to evaluate whether or not the perceived revulsion of democratic publics at "germ" warfare, for example, chemical and biological warfare, decreases the possibility that a state will pursue chemical or biological weapons. Including these variables does not change the results. Consult the Online Appendix for additional details.

Similar to previous work on the causes of nuclear proliferation, we employ event history models to investigate the correlates of CBWs pursuit in comparison to nuclear weapons pursuit. Our models estimate the likelihood that a country will pursue chemical or biological weapon in a given year (failure) given that it has not done so until this point (survived until time *t*), conditional on the set of covariates outlined above. The unit of analysis is country years beginning in 1945. Splitting each country period annually to account for the time-varying effect of our covariates generates roughly 8,951 observations over which each of the 192 countries in our analysis can potentially "fail" by initiating pursuit of a particular weapons technology or continuing pursuit in a given year. In the next section, we present the results of a multiple failure model (where a each year of failure is treated as a distinct event that can partly vary independently of success or failure in the previous period), but in the online appendix Table S4, we also demonstrate that our results are consistent when we switch to a "single failure" model where a country is coded as "failing" only in its first year of pursuit and exits the data.[12] If a country never pursues a nuclear, chemical, or biological weapon, we count that subject censored after 2000. If a country pursues a weapon for some number of years and then stops, only to start pursuing that weapon again, it reenters the risk pool in our analysis for the possibility of multiple failures.[13]

We further restrict our estimation to country-year observations in which a state has not already acquired that same technology.[14] This final restriction is important because it would be unreasonable to consider countries that have already acquired a particular weapon to be at risk of pursuing that same weapon again. Because of this final restriction, our estimates are generally based on the roughly 5,500 relevant observations at risk of failure.

Finally, to remain consistent with previous research on the causes of nuclear proliferation, we estimated parametric discrete-time hazard models using a Weibull

distribution to characterize the baseline hazard function. The positive coefficient on the ancillary shape parameter in the regressions below means that a Weibull model is appropriate since the baseline hazard appears to be increasing over time. However, we also employed Cox proportional hazard models to confirm that the results are robust to the different model assumptions (see the Online Appendix). In Tables S9.1 (nuclear), S9.2 (chemical), and S9.3 (biological), we report one possible test of the proportional hazard assumption to demonstrate that the effect of each variable on the instantaneous risk of failure does not change over time.[15] The results below are also consistent if we estimate a probit model with splines counting the number of years that countries have not pursued the relevant type of WMD (Table S5).[16]

Results

Table 3 reports the results of six different models featuring, in turn, the three different WMD technologies. Models 1 and 2 estimate the impact of chemical weapons possession (and pursuit) and biological weapons possession (and pursuit) on the instantaneous risk a state will pursue *nuclear* weapons over time. Models 3 and 4 estimate the impact of nuclear weapons possession (and pursuit) and biological weapons possession (and pursuit) on the instantaneous risk a state will pursue *chemical* weapons over time. Finally, models 5 and 6 estimate the impact of both nuclear possession (and pursuit) and chemical weapons possession (and pursuit) on the instantaneous risk a state will pursue *biological* weapons over time. In the first model specification for each type of WMD (models 1, 3, and 5), we estimate the relationship between the weapons technologies without including any other covariates. In the second model specification for each type of WMD (models 2, 4, and 6), we include a small set of covariates described previously to control for differences in the economic capacity, external security environment, treaty membership, and level of domestic unrest across cases that might affect the propensity to seek a WMD of any type.

To ease interpretation, we report hazard ratios rather than the familiar coefficient estimates from standard linear or logistic regressions. Hazard ratios are interpreted relative to 1, where hazard ratios greater than 1 indicate variables that increase the risk of weapons pursuit over time and hazard ratios less than 1 indicate variables that decrease the risk of weapons pursuit over. For example, if the results indicate that a dummy variable has a hazard ratio of 0.5, that variable decreases the risk of weapons pursuit by 50 percent, meaning it tends to be associated with a reduction in demand for that weapon type. Conversely, if a variable has a hazard ratio of 2, it doubles the risk of weapons pursuit, meaning it tends to be associated greater demand for that weapon type.

Starting with the results for nuclear weapons pursuit in models 1 and 2, the coefficients on both chemical weapons possession and chemical weapons pursuit are similarly positive and significant, suggesting that states that either possess or pursue chemical weapons are actually *more* likely to seek nuclear weapons in any given

Table 3. Impact of Nuclear, Chemical, and Biological Weapons Pursuit on Risk of Pursuing Other WMD Types, Controlling for Proliferation "Willingness."

	Dependent variable (DV)					
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Independent variables	DV: Pursuit Nuclear	DV: Pursuit Nuclear weapons	DV: Pursuit Chemical	DV: Pursuit Chemical	DV: Pursuit Biological weapons	DV: Pursuit Biological
WMD technologies						
Nuclear weapon possession			1.37e-07*** (1.03e-07)	3.20e-08*** 2.64e-08)	3.68e-09*** (2.19e-09)	1.44e-07*** (1.28e-07)
Nuclear weapon pursuit			8.033*** (4.202)	4.817*** (2.625)	2.255** (0.826)	1.986 (1.070)
Chemical weapon possession	38.18*** (24.72)	22.85*** (15.99)			24.13*** (17.06)	35.45*** (35.92)
Chemical weapon pursuit	19.90*** (10.32)	13.19*** (7.659)			14.69*** (11.07)	19.95*** (13.08)
Biological weapon possession	2.611 (1.927)	2.629 (2.328)	1.23e-07*** (1.11e-07)	4.33e-08*** (4.39e-08)		
Biological weapon pursuit	2.521** 2.611	2.507** 2.629	7.330*** (3.257)	8.311*** (3.306)		
Control variables						
GDP per capita		1.001* (0.000300)		1.000 (8.87e-05)		1.001* (0.000391)
GDP squared		1.000** (2.33e-08)		1.000* (2.37e-09)		1.000* (4.06e-08)
Alliance		1.243 (0.514)		1.589 (0.545)		0.580 (0.395)
NPT membership		0.2076*** (0.0966)				
NPT (system effect)		1.004 (0.013)				
CWC membership				0.761 (0.550)		
CWC (system effect)				0.592 (0.444)		
BWC membership						0.939 (0.497)
BWC (system effect)						0.199** (0.164)
Number land borders (security environment)		1.138* (0.0847)		1.028 (0.0805)		0.876 (0.0999)
Domestic unrest		1.054** (0.0258)		1.058 (0.0385)		0.890 (0.135)
Constant	2.45e-06*** (3.16e-06)	6.76e-08*** (3.00e-07)	7.29e-07*** (2.91e-06)	2.27e-09*** (1.56e-08)	2.56e-07*** (1.31e-06)	0*** (0)
Ancillary parameter (p)	1.182	1.409	1.489	2.083**	1.453	2.660***
Standard error (p)	(.137)	(.478)	(.396)	(.699)	(.470)	(.496)
Log likelihood	95.520046	188.43074	−88.899424	24.243336	22.780896	128.85243
Number of countries	187	165	184	162	187	171
Observations	7,263	5,802	7,059	5,635	7,376	5,921

Note: BWC = Biological Weapons Convention; CWC = Chemical Weapons Convention; GDP = gross domestic product; NPT = Non-Proliferation Treaty; WMD = weapons of mass destruction.***p < 0.01, **p < 0.05, *p < 0.1.

moment than states without these weapons. This relationship holds even after controlling for the underlying level of demand (i.e., holding constant the factors that might influence a states willingness and ability to pursue a WMD of any type). Possessing a chemical weapon increases the instantaneous risk that a state will initiate pursuit of nuclear weapons 38 times, while simply pursuing a chemical weapon increases the risk a state will initiate pursuit of nuclear weapons nearly 20 times in the data. Notice, too, that the coefficient on biological weapons pursuit is also positive and significant, suggesting that pursuit of a biological weapon is associated with a roughly 2.5 times greater risk of initiating nuclear weapons pursuit on average compared to countries that are not pursuing biological weapons. While not statistically significant, the possession of biological weapons has a similar sized impact on the likelihood of nuclear weapons pursuit, increasing the risk roughly 2.5 times.

One interpretation of these results is that neither chemical nor biological weapons possession appears to be substitutes for a nuclear capability. An example of this is Saddam Hussein's Iraq, which pursued nuclear weapons even after it acquired chemical weapons and biological weapons before the first Gulf War. Hussein attempted to utilize his chemical and biological arsenal to deter attack by regional actors both before and after the invasion of Kuwait. However, Hussein also recognized that these weapons imperfectly provided for Iraqi security in comparison to nuclear weapons. This provided a key incentive for the Iraqi nuclear program (Cigar 2011, 30). Another example is Iran today, which most analysts believe possesses chemical weapons yet still seeks to acquire nuclear weapons.

More importantly, we find evidence that merely possessing chemical or biological weapons appears to independently increase the risk of pursuing nuclear weapons because we are holding demand constant (see Table S2 in particular). States appear to treat CBWs as complements to nuclear weapons in their overall weapons arsenal, simultaneously increasing their demand for the latter when their demand for (or consumption of) either of the former increases.

It is important to recognize, however, a limitation of this inference based on our findings. These results might still suggest that the same underlying factors that lead to CBWs proliferation also lead to nuclear proliferation. That there is potentially a direct link between the weapons requires further investigation. Ultimately, we cannot say that we have identified a causal effect between the different weapons without a valid instrument to control for unobserved heterogeneity. That said, it is reasonable to think that leaders' willingness and ability to pursue different WMDs might be highly correlated across different weapons types, particularly if the process of political approval (i.e., receiving the green light to pursue more destructive WMDs from key officials) or the technical processes (i.e., weaponization) overlap such that pursuit/possession of either CW or BW decreases the marginal cost of pursuing a nuclear weapon.[17] This would be true whether states viewed CBWs as lesser versions of nuclear weapons or if they consider CBWs as relevant for different missions. The example of Saddam Hussein's Iraq and the way he leveraged his CBW

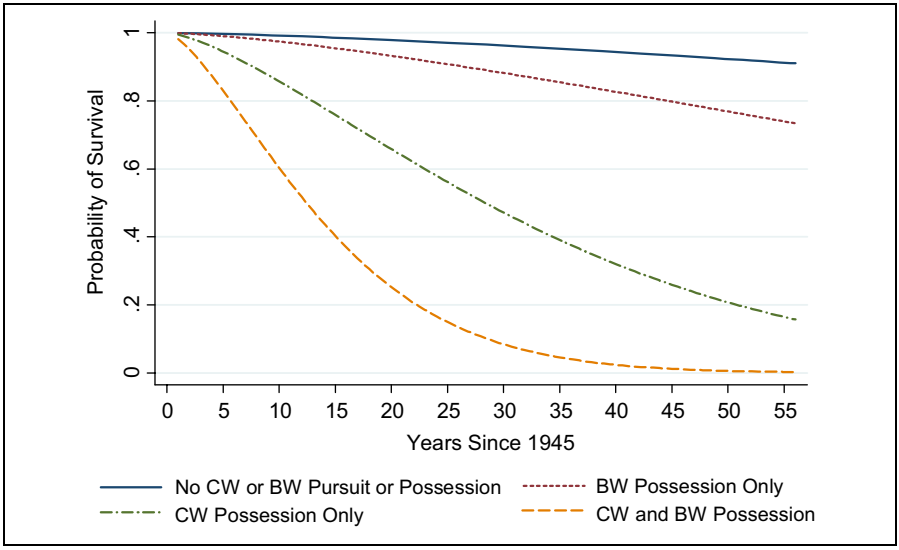

Figure 1. Survival curve for nuclear weapons pursuit.
Note: CW = Chemical Weapons; BW = Biological Weapons.

arsenal to threaten Israel and the West suggests the former (Cigar 2011), but the latter is also possible.

As a graphical illustration of these effects, Figure 1 plots the survival curve for the pursuit of nuclear weapons based on different WMD treatment conditions that are possible while holding all other covariates at their mean. The *y*-axis represents the probability of survival past time *t* (*x*-axis) conditional on surviving until time *t*, where movement down overrepresents the number of distinct failures observed at that moment in time. Survival functions that are shifted further right represent the pursuit of nuclear weapons (failure) occurring later on average, suggesting a lower demand for that weapon. Conversely, survival functions shifted to the left (closer to time zero) suggest that the pursuit of nuclear weapons occurs much sooner for that treatment condition, suggesting an increase in the demand for that weapon.

Figure 1 clearly illustrates how countries that possess both CBWs (dashed line) are more likely to pursue nuclear weapons sooner than countries with only chemical weapons (dot dash) and only biological weapons (dash), and how both of these groups pursue nuclear weapons much sooner than countries without any CBWs (solid). Notice that the median survival time for countries with both CBWs in our data is approximately ten years from the start of observation, while the median survival time for countries with only chemical weapons is closer to twenty years. This suggests that countries with CBWs not only view these weapons as insufficient to provide for their security, but that they increasingly seek nuclear weapons once they acquire chemical or biological weapons. There is some evidence that this process has

tailed off in recent years as countries like Libya (prior to the fall of Gadhafi) abandoned their nuclear pursuit even though they maintained a chemical weapons capability. One possibility is that the industrial capacity challenges associated with nuclear weapons overwhelmed the ability of a country like Libya to pursue nuclear weapons and may have influenced chemical weapons possessors such as Egypt to not pursue nuclear weapons (though other factors clearly influenced those decisions as well).

The effects of our control variables in Table 3 support conventional wisdom. Consistent with previous work, we find that a higher GDP per capita is modestly associated with a greater risk of nuclear weapons pursuit and that GDP per capita squared (included for the possibility that the relationship is curvilinear) is also positive and significant. Also consistent with previous findings, our results show that a nuclear defense pact—where a nuclear power extends a formal commitment to protect a nonnuclear state—is not associated with a lower likelihood that a state will pursue nuclear weapons. With respect to international institutions and treaty commitments, our analysis provides additional support for the claim that Non-Proliferation Treaty (NPT) membership is associated with a slightly lower risk of nuclear weapons pursuit. The strength of the NPT regime is somewhat surprisingly associated with a higher likelihood of nuclear weapons pursuit (consistent with the idea that an increasingly robust NPT facilitates the diffusion of nuclear technology).[18] Finally, a more dangerous security environment, proxied by the number of shared land borders and the level of domestic unrest, is associated with a greater risk of nuclear weapons pursuit: each additional border increases the risk of nuclear weapons pursuit by roughly 14 percent, while a one-unit increase in the level of domestic unrest is associated with a 5.5-percent increase in the risk of nuclear weapons pursuit.

Turning next to chemical weapons in models 3 and 4, we estimate the impact of both nuclear and biological weapons possession and pursuit on the instantaneous risk of initiating chemical weapons pursuit, holding demand factors constant in model 4. Model 3 shows that nuclear weapons pursuit and biological weapons pursuit are associated with an eight times and seven times greater risk of chemical weapons pursuit, respectively, while model 4 demonstrates that the sign and significance of these effects are stable after the inclusion of various controls. Like before, this positive relationship is consistent with the idea that leaders' willingness and ability to pursue nuclear or biological weapons is highly correlated with the decision to pursue chemical weapons, perhaps because the underlying process of political approval or the technical process overlaps.

Critically, we also find some evidence of substitution in the relationship between chemical and nuclear weapons, as the actual possession of nuclear weapons and biological weapons are both *negatively* associated with initiating chemical weapons pursuit in models 3 and 4. Once states finally acquire a nuclear or biological weapon, the risk that they will start to pursue a chemical weapon at any given moment in the data drops to virtually zero. This negative relationship between nuclear weapons acquisition and chemical weapons is demonstrated by several nuclear-capable states that have signed the CWC and eliminated their chemical weapons arsenals, including

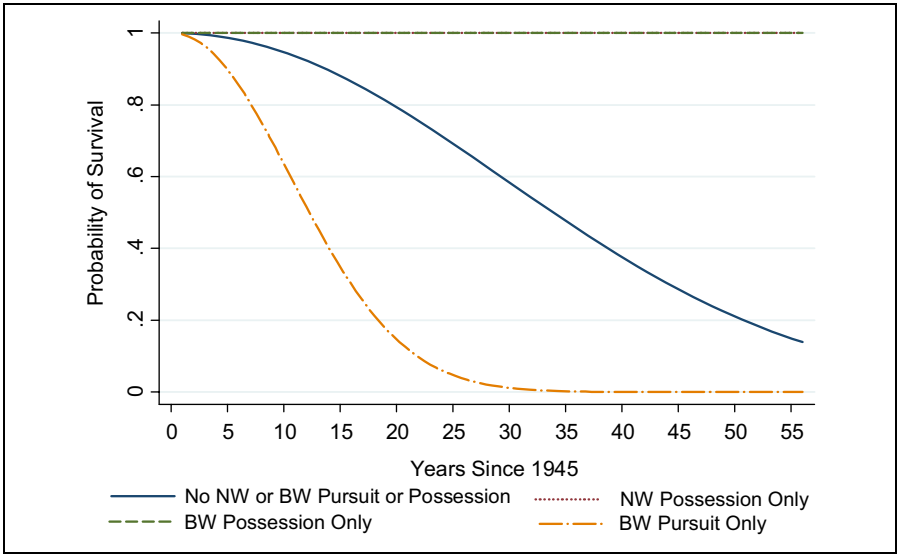

Figure 2. Survival curve for chemical weapons pursuit.
Note: NW = Nuclear Weapons; BW = Biological Weapons.

Great Britain, France, India, and the United States. Even Russia is beginning to come into compliance with its CWC obligations by eliminating its chemical weapons arsenal, a task aided by American funding beginning in 1997 with the Nunn–Lugar Act. More generally, these results are consistent with the notion that chemical weapons behave as a "poor man's atomic bomb," since nuclear weapons appear to systematically satisfy demand for chemical weapons almost entirely. Also, this relationship has become stronger in recent decades. Early in the cold war, many states possessed both chemical weapons and nuclear weapons—now, most states appear to have decided that nuclear weapons are enough. This could be due to changing norms of acceptability concerning chemical weapons or further evidence concerning the battlefield utility—or lack thereof—of chemical weapons. What may be particularly surprising, however, is that chemical weapons appear to behave as a poor man's biological weapon as well. Regardless of model specification, possessing a biological weapon reduces the risk of chemical weapons pursuit to virtually zero. This finding in particular is surprising and deserves further investigation.

Figure 2 plots the survival curve for the pursuit of chemical weapons. It demonstrates the dramatic effect of nuclear weapons acquisition on the demand for CBWs. Countries possessing nuclear weapons are at essentially zero risk of initiating pursuit of chemical over time, along with countries that have a biological weapon (these two survivor functions appear as one overlapping line). Countries pursuing biological weapons, on the other hand, still have a large desire for chemical weapons. They "fail" and pursue chemical weapons at a significantly higher rate.

The effects of our covariates on chemical weapons pursuit are similar to nuclear weapons pursuit in direction, though they often fall short of significance. For example, there is weak evidence that GDP per capita and GDP per capita squared are positively associated with a greater risk of chemical weapons pursuit (the former is statistically insignificant, while the latter is significant at the 10 percent level). However, no other covariate appears to have a statistically significant effect on chemical weapons pursuit, even though the direction on each variable fits with conventional wisdom. For example, membership in the CWC appears to be associated with a lower risk of chemical weapons pursuit, while a more dangerous external security environment and greater domestic unrest are both positively related to the risk of chemical weapons pursuit.

Finally, we turn to estimating the effect of both nuclear and chemical weapons pursuit and acquisition on the risk of initiating biological weapons pursuit in models 5 and 6. These results are equally interesting because they provide support for the notion that biological weapons (in addition to chemical weapons) can also be appropriately considered a "poor man's nuclear bomb." Similar to the impact of possessing nuclear weapons on the probability a state pursues chemical weapons, nuclear weapons possession has a strong negative effect on biological weapons pursuit in both models 5 and 6. After holding the underlying level of demand constant in model 6, simply possessing a nuclear weapon appears to decrease the instantaneous risk that a state will pursue biological weapons to virtually zero (1.44×10^{-7}). This is consistent with the understanding of nuclear weapons as so powerful that they make the possession of other types of WMDs less relevant. Even before countries such as the United States abandoned their chemical weapons programs, for example, they abandoned their biological weapons program. The United States eliminated its offensive BW program under a Nixon administration order in 1969 and had shut down the program by the time it signed the BWC in 1972. France and Great Britain similarly eliminated their offensive BW programs. Russia stands in stark contrast to this argument, however. Evidence revealed after the cold war demonstrated that the Soviet Union maintained a vibrant offensive BW program at the Biopreparat complex through the end of the cold war. This demonstrates that grouping CBWs into a single category may not accurately represent the way countries actually think about them. Biological weapons, given their greater theoretical destructive capacity, may be considered somewhat differently. This is a potential path for future research.

In contrast to the general relationship between nuclear weapons acquisition and biological weapons pursuit, nuclear weapons *pursuit* is associated with 2.25 times greater risk of biological weapons pursuit in this earlier stage development. Chemical weapons, on the other hand, appear to have the effect of stimulating biological weapons pursuit at both the possession and pursuit stage, consistent with a complements interpretation.

Figure 3 plots the survival curve for the pursuit of biological weapons and shows that a similar pattern exists for biological weapons pursuit that exists for chemical weapons. After controlling for the factors that might cause states to seek a WMD,

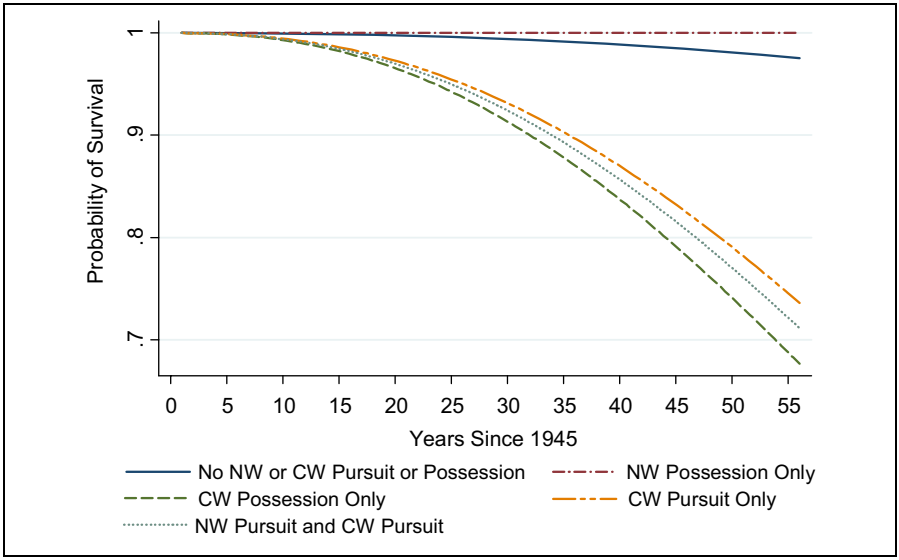

Figure 3. Survival curve for biological weapons pursuit
Note: NW = Nuclear Weapons; CW = Chemical Weapons.

the acquisition of a nuclear weapon reduces demand for a biological weapon to virtually zero, such that these states with a nuclear weapon are even less likely to pursue a biological weapon than are states without a WMD of any kind.

However, Figure 3 also reveals two additional features of biological weapons proliferation. First, comparing Figures 2 and 3 shows statistically a fact evident in Tables 1 and 2—countries have pursued chemical weapons at a much higher rate in general than biological weapons. This potentially suggests biological weapons are much harder to acquire, but it also could demonstrate that there is even more uncertainty when it comes to how countries would actually utilize biological weapons in a conflict. Second, we add an extra curve to Figure 3 to depict how the joint pursuit of chemical weapons and nuclear weapons influences the probability that a country pursues biological weapons. Note that the probabilities of pursuit are extremely similar across three conditions: chemical weapons pursuit, nuclear and chemical weapons pursuit, and chemical weapons possession. This demonstrates that biological weapons are clearly perceived as "superior" weapons, in many ways, to chemical weapons. If chemical weapons were a plausible substitute for biological weapons, we would expect the probability of biological weapons pursuit to decline significantly as a country shifted from pursuing chemical weapons to acquiring chemical weapons.

For the most part, the effects of the covariates for biological weapons in Table 3 are similar to other types of weapons. GDP per capita and GDP per capita squared are positively associated with a greater risk of chemical weapons pursuit, while membership in the BWC appears to be associated with a lower risk of biological weapons pursuit

(though only the system effect is significant). This is surprisingly strong evidence that a growing norm against the use of biological agents in warfare had a powerful effect on the pursuit of biological weapons. An increasingly dangerous external and internal security environment appears to be negatively correlated with biological weapons pursuit over time, though this effect is not statistically significant in the data.

In summary, our findings suggest that, at a given level of demand, CBWs appear to be treated as complements to nuclear weapons, as pursing or possessing either of the former appears to increase the demand for the latter among countries that have yet to initiate pursuit. The same can roughly be said about chemical weapons: pursuing either nuclear or biological weapon appears to increase the demand for chemical weapons, suggesting that the former serve as complements to the latter at the pursuit stage. However, the most interesting finding that emerges from our analysis is that the actual possession of nuclear reduce the likelihood a state will continue to pursue chemical weapons or biological weapons to virtually zero. This result is remarkably consistent with the popular notion that CBWs are essentially a poor man's atomic bomb, as nuclear weapons significantly reduces the likelihood a state will initiate pursuit of a new biological or chemical weapon at any moment. A key driver of our findings is that states that acquire nuclear weapons are increasingly comfortable abandoning their CBWs programs.

These results are also interesting when combined with the nuclear results because they demonstrate that the substitution only goes one way. The fact that acquiring chemical or biological weapons does not decrease the risk of nuclear pursuit, but acquiring nuclear weapons decreases the risk of chemical and biological pursuit suggests that nuclear weapons appear to substitute for biological weapons, but CBWs do not substitute for nuclear weapons.

Conclusion

Policy makers around the world are concerned about the scope and impact of the proliferation of WMDs. To date, however, scholarly attention has focused almost exclusively on the causes and consequences of nuclear proliferation. Yet, many states that lack nuclear weapons possess biological or chemical weapons instead. For all the research conducted over the last half-century on the reasons leaders acquire nuclear weapons, we still know surprisingly little about the determinants of CBWs proliferation. In this article, we explored the proliferation of different types of WMDs in concert. Our findings have critical implications for both the academic literature on proliferation and those interested in real-world consequences.

First, we find that very similar factors seem to drive the proliferation of nuclear, biological, and chemical weapons. Second, countries do distinguish between nuclear weapons and other types of WMDs. While countries pursuing nuclear weapons are likely to pursue other types of WMDs as well, once a country acquires nuclear weapons, things change. Countries that have nuclear arsenals appear much less likely to initiate pursuit of biological weapons and even chemical weapons. This result is

especially sensible and fits with critical historical examples. After all, one of the reasons the United States abandoned biological weapons in 1969 and agreed to eliminate its chemical weapons arsenal in 1993 was the overwhelming power of America's nuclear arsenal. Our results suggest that this is not just an artifact of the United States, but a more generalizable phenomenon.

Together, these findings also have important implications for nonproliferation policy. First, by demonstrating that many of the same factors that drive nuclear weapons proliferation also constitute a systematic explanation for CBWs pursuit, our results should help policy makers identify proliferation risks before they actually materialize. Second, determined proliferators seem able to acquire biological and especially chemical weapons with great effort. In contrast, acquiring nuclear weapons represents a much greater challenge. Third, by providing some empirical evidence that CBWs can be accurately characterized as the "poor man's atomic weapon," our results should help policy makers reallocate resources away from low-risk CBW proliferators upon observing the acquisition of nuclear weapons. While states tend to pursue each type together, possession of nuclear weapons appears to satisfy states underlying security demands and significantly reduces the risk of CBWs proliferation. For international relations scholars, we hope this first cut at estimating the relationship between nuclear, biological, and chemical weapons proliferation is suggestive and that it catalyzes future research.

Authors' Note

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Notes

1. For the purposes of this article, we define weapons of mass destruction as nuclear, biological, and chemical weapons.
2. We define chemical weapons using the United Nations definition, as "chemical substances, whether gaseous, liquid, or solid, which might be employed because of their direct toxic effects on man, animals and plants" (Spiers 1994, 1).
3. For the purpose of this article, we define biological weapons as they are in the 1972 Biological Weapons Convention (Convention on the Prohibition of the Development 1972).
4. We also run our main tests in Table 3 using the Bleek data for nuclear weapons possession and pursuit to see if our results were robust to these different codlings. Appendix Table S8

shows that the direction, rough magnitude, and statistical significance for the coefficient estimates on our main independent variables are all the same.

5. In addition to the sources cited above, Horowitz consulted several experts in 2004 to help assemble this data set.
6. A description of our data collection efforts and a complete list of sources and coding decisions is available in the Online Appendix.
7. We recognize that there is a wide degree of variation in the lethality of weaponized chemical and biological weapons. Pursuit could mean different things across cases if a country has chlorine weapons, for example, but seeks to acquire VX gas. Similar distinctions exist for biological weapons. Thus, lumping all of these weapons together places some limitations on our results. Our models implicitly assume some sort of similarity within weapons types. This is a similar assumption to that made by studies of nuclear proliferation that do not distinguish between atomic and hydrogen bombs.
8. Starting our analysis in 1945 raises the potential of left censoring, as we initially exclude a number of important cases because they already had ongoing chemical and biological weapons (CBW) programs at the time the analysis starts. However, we investigated this, and found that most of the countries that failed before 1945 later gave up these weapons within our study period and reentered our risk pool. As a result, our estimates are based, in part, on the behavior of these cases. For example, in the case of Biological Weapons, four of the five countries that failed before observation begins eventually gave up biological weapons and reentered our pool: United States (in 1974), United Kingdom (in 1956), France (in 1973), and Japan (in 1945). Similarly for chemical weapons, eight of the eleven possessors gave up the weapon and reentered our pool (Czechoslovakia, Greece, Hungary, Japan, Poland, Spain in 1945, Canada in 1946, United Kingdom in 1957), while all three chemical weapons pursing countries also stopped pursuing during our observation period and reentered our risk pool—Sweden in 1945, Egypt in 1962, and Australia in 1973.
9. We also tested the robustness of our codings by excluding the P5 nuclear powers, with the thought that they might distort the results. We also recoded specific countries as 0 if we viewed the source data as sufficiently inconclusive. One example of this is Saudi Arabia. Neither check changed the results.
10. Given potential endogeneity concerns, we verified the results are the same if we exclude this variable.
11. Including all of the treaties in the same model, for example, whether a country signed the Biological Weapons Convention (BWC), Chemical Weapons Convention (CWC), and/or Non-Proliferation Treaty (NPT), along with system-wide participation, did not change the results.
12. As an additional robustness check, we also rerun our analysis on the subsample of failed cases to show that many of our explanatory variables are oppositely correlated with abandonment of a program in Table S10.
13. Countries that previously acquired a particular weapons of mass destruction (WMD) technology, only to subsequently give it up reenter the risk pool in our analysis. This could bias the results. In Table S7, we generate a dummy variable to mark countries that previously possessed relevant NBC (Nuclear, Chemical and Biological) capabilities. It does not change our results.

14. For example, when modeling the factors that make countries more likely to pursue chemical weapons, we exclude countries that have already acquired chemical weapons. This actually biases against our theory—including them strengthens the results.
15. The Cox model assumes that the effect of each variable on the instantaneous risk of failure does not change over time. To confirm the effect of each variable was essentially constant over time, we interacted each of the covariates with analysis time to verify that the effect of these interactions is not significantly different from zero in Tables S9.1 through S9.3. Notice in nearly all cases, the effect of the interaction term for each of our main independent variables (reported in the adjacent column for the base model and the more complicated model) is not statistically significant. In the few cases where the interaction is significant, the size of the effect is so small that it is substantively indistinguishable from 1.
16. We also created a time counter to measure the number of years a country has possessed a particular BC weapons capability, building on Horowitz's (2009) finding that experience with nuclear weapons influences militarized behavior. See Table S6. Controlling for the length of time a country has possessed a BC weapons capability does not undermine our results and suggests some pathways for future research.
17. Identifying a valid instrument is likely to be an insurmountable task because almost every observable factor correlated nuclear weapons pursuit is likely to be correlated with the risk of chemical and biological weapons pursuit. Tables S1 and S2 demonstrate that the effects hold even after inclusion of a full vector of covariates identified in the previous literature to approximate for latent levels of weapons of mass destruction (WMD) "demand," which might produce both outcomes. Even still, we acknowledge that the nature of the analysis limits our ability to draw a causal inference.
18. To test this idea, we added a measure of the number of years since 1945 into our model. This did not change the results. We also estimated models excluding the countries that possessed in 1945 due to World War II arsenals, and the results were consistent.

Supplemental Material

The online appendices are available at http://XXX.sagepub.com/supplemental.

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