Journal of Conflict Resolution

http://jcr.sagepub.com/

The Determinants of Nuclear Force Structure

Erik Gartzke, Jeffrey M. Kaplow and Rupal N. Mehta

Journal of Conflict Resolution 2014 58: 481 originally published online 6 December 2013
DOI: 10.1177/0022002713509054

The online version of this article can be found at:
http://jcr.sagepub.com/content/58/3/481

Published by:

SAGE

http://www.sagepublications.com

On behalf of:

Peace Science Society (International)

Article

Journal of Conflict Resolution
2014, Vol. 58(3) 481-508

DOI: 10.1177/0022002713509054
jcr.sagepub.com

The Determinants of Nuclear Force Structure

Erik Gartzke[1], Jeffrey M. Kaplow[1], and Rupal N. Mehta[1]

Abstract

A substantial literature examines the causes of nuclear proliferation, but few studies have addressed why states decide on a particular portfolio of weapon systems once they have acquired a basic nuclear capability. We advance a portfolio theory of nuclear force structure, positing that states seek a diverse set of capabilities for nuclear deterrence, but that they also face major resource and organizational constraints. A number of factors may help to explain the portfolio of nuclear forces that states ultimately field, including resource availability, experience as a nuclear power, bureaucratic politics, the conventional threat environment, the presence of nuclear rivals, and the maintenance of nuclear alliances. We test the influence of these factors on force structure using a new data set of nuclear weapon platforms fielded by nine nuclear nations between 1950 and 2000. Our findings represent an important step in understanding the drivers of nuclear behavior after states have joined the nuclear weapons club.

Keywords

nuclear weapons, force structure, weapons platforms, missiles

States that have acquired nuclear weapons must confront the complicated and important question of how to structure their nuclear arsenals.[1] Some states, such as the United Kingdom, field only a small number of nuclear platforms, while others, such as the

[1] Department of Political Science, University of California, San Diego, La Jolla, CA USA

Corresponding Author:

Jeffrey M. Kaplow, Department of Political Science, University of California, San Diego, 9500 Gilman Drive, La Jolla, CA 92093, USA.
Email: jkaplow@ucsd.edu

United States and the Soviet Union, establish diverse portfolios of weapons with varying range, destructive power, and other characteristics.[2] Nuclear states differ dramatically not only in the number of nuclear platforms they deploy but also in the relative weight they place on particular weapon systems and on each component of the nuclear triad (air-, land-, and sea-based weapons).[3] These characteristics have also changed over time—nuclear forces that seem appropriate in one strategic environment may be made redundant or obsolete by the introduction of new technologies or by cycles of crisis and détente. Variation across nations and time raises several key questions: Why do states deploy the nuclear force structures they do? What drives the decisions of states to invest in new nuclear platforms? How do officials think about the diversification of their nuclear portfolios?

The answers to these questions are important both theoretically and in practice. The diversification of nuclear forces is intimately tied to conceptions of nuclear deterrence, secure second-strike capability, and mutually assured destruction. A particular force structure may be more or less vulnerable to preemptive attack, more or less effective at targeting opposing forces, and more or less capable of mobilizing quickly in the event of crisis. It has long been believed, for example, that fielding a diverse set of platforms covering each leg of the nuclear triad reduces vulnerability to sudden attack, even as it increases the flexibility of possible responses. If force structure is indeed an important element of deterrence effectiveness, then the determinants of a state's nuclear forces may mean the difference between sustained peace and a nuclear crisis.

Nuclear force structure is not just a relic of Cold War thinking. There remains a lively policy debate about the role of nuclear forces in an era of US nuclear supremacy (Flory 2006; Lieber and Press 2006, 2009; Payne 2006). Force structure has also played an important role in policy discussions surrounding the New START Treaty (Pifer 2010), calls for the move toward "Global Zero" in which the number of nuclear weapons is dramatically reduced or eliminated (Cortright and Väyrynen 2010; US Department of Defense 2010), and ongoing work to ensure the reliability of the US nuclear deterrent into the future (Chyba and Crouch 2009). India and Pakistan also grapple with how their nuclear postures affect deterrence in a context very different from the Cold War standoff between the United States and the Soviet Union (Narang 2010).

Despite the obvious relevance of these issues, academic research on nuclear arsenals has primarily sought to explain horizontal proliferation and the effect of a larger number of nuclear weapon states on the international system. Here, we attempt to remedy this situation by considering both the theoretical and empirical determinants of nuclear force structure. We proceed in five parts. First, we briefly review existing studies of nuclear proliferation and force structure. Second, we present a theoretical framework in which to understand the various factors that might influence the nuclear force structure decisions of states. Third, we introduce an original data set compiled for this analysis and present several quantitative models of nuclear force structure. We report our findings in the fourth section. Finally, we conclude with suggestions for future research into the dynamics of nuclear force structure decisions.

Existing Approaches

Most studies of nuclear proliferation address why and how states build or acquire initial nuclear capabilities (Jo and Gartzke 2007; Sagan 1996; Singh and Way 2004; Solingen 1994) or the effect of proliferation on international security (Asal and Beardsley 2007; Beardsley and Asal 2009; Gartzke and Jo 2009; Sagan and Waltz 1995). These studies provide a broad framework for understanding the causes and consequences of horizontal proliferation. A recent wave of quantitative work has built on this framework, focusing on one or two specific factors that lead states to seek nuclear capabilities (Gartzke and Kroenig 2014). This work emphasizes both supply-side factors, including access to external nuclear assistance (Brown and Kaplow 2014; Fuhrmann 2009; Kroenig 2009), and demand-side factors, such as defense pacts with nuclear states, the forward deployment of weapons, or the availability of alternative weapons of mass destruction (Bleek and Lorber 2014; Horowitz and Narang 2014; Fuhrmann and Sechser 2014). Some scholars have sought to link nuclear force structure decisions of existing nuclear states to decisions by other states to proliferate (Tago and Singer 2011), but little recent work addresses the determinants of vertical proliferation itself.

An established literature on organizational dynamics and bureaucratic politics, much of it written in the context of the Cold War superpower rivalry, offers one approach to understanding nuclear force structure. Authors in this tradition argue that militaries, like other organizations, have a preference for the status quo; any push for adaptation or change is generally resisted by entrenched interests (Allison and Morris 1975; Halperin 1974; Perrow 1986; Sagan 1994; Waltz 1990). Given that technological change and the introduction of new missions or weapons can threaten the status quo, military organizations have incentives to delay these developments and instead protect the existing distribution of resources and power (Halperin 1974; Sagan 1996).

Evidence for bureaucratic inertia can be gleaned from incidents such as the introduction of second-strike survivable forces in the United States, which only came about after significant pressure from civilian authorities. US naval leaders opposed the introduction of submarine-launched ballistic missile (SLBM) systems, for example. According to Sapolsky (1972), "the major impediment to development of the Polaris missile system was the Navy's indecisiveness about sponsoring a ballistic missile program." Given the Eisenhower administration's projected budget cuts, senior naval officials were concerned that the new class of naval nuclear weapons would threaten the maintenance of forces central to the Navy's traditional missions.

Another literature points to arms racing as an explanation for nuclear forces. Richardson (1960) argued that "fear of opponent's weapons and capability generally, without an agreement, would lead to an arms race to ensure stable deterrence." According to this perspective, fear of enemy nuclear capabilities and the push for an effective deterrent against any rival state precipitates development of an offensive strategic nuclear force. Alain Enthoven, an aide to Robert McNamara, summarized the "official position" of the superpowers, "it is important to understand this iteration of opposing strategic forces and its relation to the strategic force planning process. If the overriding objective of our strategic nuclear force is to deter a first strike against us, the United States must have a second-strike capability. This action-reaction phenomenon is central to all strategic force planning issues as well as to any theory of an arms race" (Enthoven and Smith 1971; Kugler, Organski, and Fox 1980).

This arms racing explanation extends beyond the US–Soviet rivalry to describe the tense relationship between India and Pakistan. According to Chari (2001), the need for a triad to establish a survivable nuclear force, and subsequent interservice rivalry, accelerated South Asian tensions. Narang (2010) sees nuclear force structure in the context of the nuclear postures both states employ in order to effectively deter their rival.

Still another body of work addresses the causes and consequences of conventional force modernization, military technology development, and the acquisition of new capabilities such as ballistic missiles (Barkley 2008; Bas and Coe 2012; Eyre and Suchman 1996; Mettler and Reiter 2012; Rosen 1991; Sechser and Saunders 2010). Sechser and Saunders (2010), for example, find that the mechanization of a state's military depends more on its security environment than on its domestic institutions. Mettler and Reiter (2012) and Barkley (2008) find similarly that the presence of ballistic missiles in a neighboring state is a significant driver of a country's decision to acquire missile technology. Because nuclear forces piggyback on conventional capabilities—aircraft, submarines, and missile technology—there is likely to be some overlap between the determinants of conventional military modernization and those of nuclear force structure.

While these literatures introduce important ideas about the drivers of nuclear force structure, this work often focuses on single case studies and rarely tests these theories in a systematic way. By focusing mainly on a small number of cases, existing research may also miss some important trade-offs that states must face in fielding an entire arsenal of nuclear weapon systems. In the next section, we advance a portfolio theory of nuclear force structure that seeks to fill the gap between existing analytical conceptions.

A Portfolio Theory of Nuclear Force Structure

Policy makers may have numerous goals in mind when making decisions about nuclear force structures. States, for example, may seek out particular capabilities through the acquisition of individual nuclear platforms. Nuclear platforms vary in terms of range, destructive power, vulnerability to attack, effectiveness against different kinds of enemy forces, and other important attributes. The capability of an individual nuclear platform, however, is not the whole story. If a given weapon system dominated all others on every metric, nuclear arsenals might emphasize a single delivery vehicle. In reality, states must consider the totality of their nuclear capabilities, and so look to diversify arsenals, creating a portfolio of platforms that best achieves state goals.

Diversification is advantageous for defensive reasons. Lacking experience with nuclear conflict, nations cannot know which weapons will prove most effective or most vulnerable on the battlefield. Emphasizing a particular nuclear platform increases the risk that nuclear forces will become vulnerable to enemy counterforce targeting or other measures or even to unforeseen or accidental logistical or maintenance problems (Sagan 1993). This is one of the fundamental justifications for the nuclear triad. According to former Secretary of the Air Force, Thomas Reed, "Its diversity poses an insoluble targeting problem to any aggressor. Any attack that might seriously cripple one leg of the Triad constitutes a clear and unambiguous warning to the other two. There is no known way to attack all three simultaneously" (McCarthy 1976).

Diversification may also hold benefits for the offense, by facilitating attacks on a range of different enemy forces and by complicating the challenge faced by an opponent seeking to limit its vulnerability (Burt 1978; McCarthy 1976; Snow 1979). Diversification allows one weapon system to compensate for weaknesses in another. Strategic bombers, for example, while more flexible and dispersed than intercontinental ballistic missiles (ICBMs), are vulnerable to air defenses in a way that missile systems are not. Submarine-launched systems, in turn, are more difficult for an adversary to hold at risk but pose additional challenges for command and control. By fielding weapon systems of different types, states also demand more from an opponent trying to defend against attack. This is a significant advantage of diversification; an adversary may decline to invest in air defense, for example, knowing that a state can also bring missile systems to bear. The presence of the missile system, then, may actually increase the potential offensive power of air assets in the portfolio.

Diversification inoculates offensive capabilities against potentially disruptive defensive technologies. New advances in missile defense systems, for example, are less worrying if a state also fields strategic air assets. Diversified nuclear portfolios further hedge against unanticipated changes in the strategic environment. The weapon system best able to hold a fading adversary at risk might be less effective in deterring the next rising opponent. Having forces of different types and capabilities minimizes the risk that a nuclear portfolio will become obsolete.

Of course, portfolio diversification is costly. The development of nuclear platforms with unique capabilities calls for economic and technical resources that may be in short supply. These costs may go beyond those associated with developing a different type of missile; platforms are often designed specifically for a particular physics package—the nuclear component of the overall weapon—and the costs of fielding new nuclear weapon designs can be substantial. New nuclear platforms also carry significant opportunity costs. Investments in nuclear development may displace funding for conventional military weapons as well as other national priorities.

Some kinds of diversification may simply be beyond a state's technical capabilities or may require military or civilian infrastructure that a state does not possess. SLBMs, for example, require a submarine and extensive naval infrastructure. Limited naval capabilities may help to explain a state's decision not to develop submarine-launched nuclear platforms. Long-range missile systems pose their own technical challenges, and the difficulty of mastering missile technology may limit the extent to which a state can diversify its nuclear portfolio.

Finally, diversification may have significant consequences when it comes to the structure of military organizations and a nation's command and control capability. Military organizations may resist nuclear weapons if commanders see them as distracting from their traditional mission, or they may covet nuclear weapons as a signal of prestige and organizational power (Sagan 1996). In either case, extending nuclear weapons to a different branch of the military (as states are forced to do, e.g., when they first deploy SLBMs) is potentially fraught with political complications. Diversification also places additional stress on nuclear command and control mechanisms. Ensuring effective government control of nuclear weapons and guarding against unauthorized or accidental use is challenging enough when all nuclear weapons are tightly held within a single military organization. Dispersing weapons across organizational boundaries makes it more difficult to maintain positive control and targeting (Kak 1998; Younger 2000).

There are several ways to explain the structure of nuclear forces, given the advantages and disadvantages of a diversified nuclear portfolio. These explanations can be organized as domestic constraints, bureaucratic politics, conventional threats, nuclear rivalries, and nuclear alliances.

Domestic Constraints

One of the most basic determinants of the diversification of a state's nuclear force structure may be the state's underlying capacity. States that lack advanced technology face additional hurdles in developing nuclear-armed ballistic missiles, while states without submarines cannot field SLBMs. Capacity limitations that inhibit the development of new military capabilities are also likely to limit the diversity of nuclear forces. Such constraints may be a function of the economic strength of the state, or states may lack the resources or expertise necessary to miniaturize and mass-produce the sophisticated nuclear physics packages that can be mated to advanced weapon platforms. Specific weapon systems also require infrastructure that may not be available—from advanced command and control mechanisms to a trained officer corps. Military resources place critical limits on how diverse nuclear force structures can become.

Resources Hypothesis: Diversification of nuclear forces should increase with greater levels of economic, technical, and military resources.

These kinds of capacity limitations point to another potential driver of diversified nuclear forces: the passage of time. Several aspects of nuclear force structure, such as necessary military infrastructure or nuclear design expertise, develop over time. Even conventionally sophisticated states are unlikely to be fully ready for a diversified nuclear portfolio from the moment that they enter the nuclear club. It may be that nuclear states follow a common trajectory; for example, they may initially press conventional forces into service as nuclear delivery vehicles (typically heavy bombers and attack aircraft) before slowly developing a more diverse set of nuclear platforms. States may eventually reach a kind of force structure equilibrium at nuclear maturity, in which new forces are deployed only to replace aging and obsolete forces of equivalent type.

Evolving nuclear force structures may reflect more than just the passage of time, however. States may also gain experience with nuclear weapons, learning to manage nuclear deterrence. Deterrence is more effective if forces are less vulnerable to attack, and when the promise of a retaliatory counterstrike is most credible. Part of the learning process for nuclear states might involve adopting nuclear force structures that are more adept at deterring aggression. Horowitz (2009) finds that new nuclear weapon states are more conflict prone, but that over time nuclear weapon states become less likely to engage in disputes than states without nuclear weapons. One possible explanation for this result is that states adjust to their newfound nuclear status by diversifying their nuclear forces to more effectively deter external aggressors.[4]

Maturity Hypothesis: Diversification of nuclear forces should increase as a state gains experience with nuclear weapons.

Bureaucratic Politics

The decision to diversify nuclear forces may be imposed on the military from civilian leaders or other government officials. The extant literature argues that militaries, like other organizations, have a preference for the status quo. Military organizations have an incentive not to pursue new missions and technologies and instead to protect the existing distribution of resources and power. In short, stronger military organizations are likely to present obstacles to the timely diversification of nuclear portfolios.

Bureaucratic Politics Hypothesis: Diversification of nuclear forces should decrease as a military bureaucracy grows stronger.

Conventional Threats

Scholarship on the determinants of nuclear proliferation indicates that when states feel threatened, even by conventional forces, they are more likely to develop nuclear weapons (Singh and Way 2004; Jo and Gartzke 2007). Conventional threats may also have an effect on states' decisions to diversify their nuclear portfolios. The ultimate direction of this effect, however, is unclear.

On one hand, states facing greater conventional threats may seek more diversified nuclear portfolios to augment their conventional deterrent. Nuclear weapons loom in the background of any contest with a nuclear state, and a more diverse nuclear force posture may make potential aggressors less willing to test the credibility of the implicit nuclear threat. North Atlantic Treaty Organization commanders, for example, argued during the Cold War that a secure second-strike capability was essential for both conventional and nuclear deterrence of the Warsaw Pact (Lebow and Stein 1995). A more diversified portfolio may also spillover to conventional military power, strengthening command and control and channeling resources to military assets that can be used for both conventional and nuclear missions, such as submarines. States in a more threatening environment may choose to diversify their nuclear portfolios partly to take advantage of these positive externalities.

Conventional Deterrence Hypothesis: Diversification of nuclear force structure should increase as states face greater conventional threats.

On the other hand, the substantial opportunity costs that attend the development of new nuclear platforms may dissuade threatened states from investing in a diverse nuclear portfolio. For a state in a dangerous neighborhood, the cost of a new nuclear missile might be better spent on conventional military capabilities. This is especially true if possession of nuclear weapons does not make conventional conflict significantly less likely, as some studies have found (Gartzke and Jo 2009). The presence of substantial conventional threats may thus lead states to prioritize conventional military improvements over the diversification of their nuclear portfolios.

Opportunity Cost Hypothesis: Diversification of nuclear forces should decrease as states face greater conventional threats.

Nuclear Rivalries

A state's decision to pursue a particular distribution of nuclear platforms may be influenced by the presence of a nuclear rival and by the configuration of the rival's forces. A simple arms racing logic suggests that a state will increase the diversification of its portfolio in response to a more diversified opponent. Yet if states respond to their adversaries' force structures, the nature of that response may be far more complex. Nuclear platforms of different types and capabilities may be required when an opponent increases the overall size of its nuclear arsenal, for example. The geographic distance between rivals may also play a critical role in determining force structures. Neighboring rivals can reach each other with any weapon system, while distant adversaries require a diverse set of nuclear platforms—long-range bombers, submarines, ICBMs—to hold a rival's homeland at risk. Finally, a state's level of diversification may depend on relations with nuclear rivals. As tensions ease, nuclear forces may target other potential adversaries or contribute to confidence building in the wake of détente. When the next crisis mounts, the nuclear portfolio may again shift to weapons that best target an enemy's forces.

Arms Race Hypothesis: Diversification of nuclear forces should increase with the presence of a rival, as a rival's nuclear forces become more diversified, or as a rival's nuclear forces increase in capability.

Rival Distance Hypothesis: Diversification of nuclear forces should increase with the geographic distance of a nuclear rival.

Crisis Hypothesis: Diversification of nuclear forces should increase as disputes between two rivals increase.

Arms control treaties figured prominently in the US and Soviet nuclear rivalry. Both the United States and the Soviet Union altered their arsenal sizes and their portfolio allocation in the wake of the Strategic Arms Limitation Talks (SALT) and Strategic Arms Reduction Treaty (START). START I barred its signatories from deploying more than 6,000 nuclear warheads atop a total of 1,600 ICBMs, SLBMs, and bombers. These general reductions may have resulted in significant changes in the number of different weapon systems deployed. New START, ratified in 2010, further limited the number of ICBM launchers, SLBM launchers, and heavy bombers to 800. This agreement has already yielded a change in projections of the future diversification of the US nuclear portfolio (Collina and Kimbal 2010). While these agreements have complex effects, one significant outcome of arms control efforts may be a reduction in the number of different nuclear platforms in the field and a corresponding reduction in the diversification of nuclear portfolios.

Arms Control Hypothesis: Diversification of nuclear forces should decrease in response to arms control treaties.

Nuclear Alliances

Alliances between nuclear states may drive force structure decisions in opposing ways. First, states may construct nuclear force structures that complement the nuclear portfolios of their allies. If states consider the totality of nuclear forces within the alliance, then they should structure their own forces to mitigate weaknesses in the collective portfolio. If, for example, an ally boasts a highly concentrated force structure, then the state may seek to diversify, while a well-equipped ally may alleviate the need for a state to seek diversity in its own forces. In the latter case, the state may be seen as free riding on the nuclear investments of its ally.

Complements Hypothesis: Diversification of nuclear forces should decrease with the presence of a nuclear ally, as an ally's nuclear forces become more diversified, or as an ally's nuclear forces increase in capability.

Alternatively, alliance relationships may push states to create nuclear forces in the same image as their allies. This may reflect a desire to standardize capabilities with alliance partners, to facilitate economies of scale, and to improve the interoperability of allied militaries. Duplicating force structures may also result unintentionally from technology transfer. Allies are more likely to share weapons technology, causing partners to develop similar weapon systems. If this dynamic holds sway, having an ally that fields a diverse range of nuclear platforms might lead a state to diversify its forces in comparable ways, even deploying comparable platforms.

If states adjust their force structures to counter rivals, however, then mirror imaging among the force structures of allies may owe more to the presence of a common adversary than to alliance dynamics. Faced with similar external threats, it would not be surprising to see allied states take similar approaches to efficiently and effectively deterring their adversaries.

Mirror Image Hypothesis: Diversification of nuclear forces should increase with the presence of a nuclear ally, as an ally's nuclear forces become more diversified, or as an ally's nuclear forces increase in capability.

States offering a credible nuclear umbrella must ultimately be capable of coming to the aid of their allies. The nuclear force structure required to do so may depend, as in the case of nuclear rivalry, on the ally's geographic distance. More diversified forces may be necessary to reach distant allies, while nearly any weapon system could be relevant to a nearby conflict.

Ally Distance Hypothesis: Diversification of nuclear forces should increase with the geographic distance of a nuclear ally.

Testing the Determinants of Nuclear Force Structure

To analyze the determinants of nuclear force structure, we created a new data set of nuclear platforms with annual observations for nine nuclear states between 1950 and 2000.[5] Data were obtained from several secondary sources, including the National Resources Defense Council's *Nuclear Weapons Databook* (Cochran, Arkin, and Hoenig 1984; Cochran et al. 1989; Norris, Burrows, and Fieldhouse 1994), the *Air Force Digest* (US Air Force), Stockholm International Peace Research Institute's annual *yearbook (Stockholm International Peace Research Institute 1968), and the Military Balance* from the International Institute for Strategic Studies (1963). Country-specific sources were also consulted.[6]

This data set can help us understand how states develop and maintain a portfolio of nuclear weapon assets. One important aspect of portfolio maintenance is the

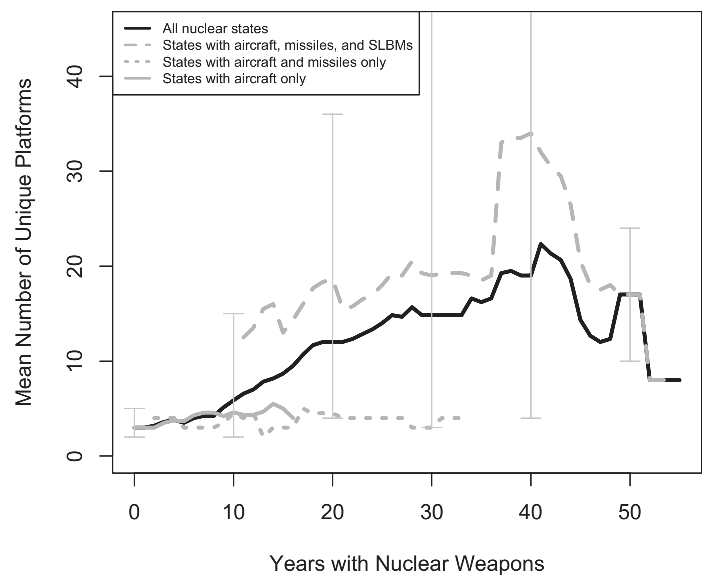

Figure 1. Unique nuclear platforms over time

development of different types of nuclear platforms. In their early years, nuclear nations steadily develop a number of new nuclear-specific platforms to support their nuclear deterrent, but the number of unique platforms seems to level off as states reach nuclear maturity. Platforms are still being created, but these are mostly produced to replace existing platforms that are then retired from service. This trend from adolescent to mature force structure is shown in Figure 1.

The solid black line in Figure 1 represents the average number of unique platforms for all nuclear weapon states at a given level of nuclear experience.[7] The general trend is a slow increase in the number of unique nuclear platforms from nuclear acquisition to about thirty years of nuclear experience, when the trend line begins to level off. Fluctuations at just over forty years of nuclear experience correspond with US and Russian force structure changes at the end of the Cold War. The number of unique platforms is contingent, however, on the types of delivery vehicles the state deploys. The solid gray line in Figure 1 shows the average number of unique platforms among states that employ only aircraft as delivery vehicles; the dotted line represents states with both aircraft- and land-based missiles, and the dashed gray line represents states with the full nuclear triad—aircraft, land-based missiles, and SLBMs.[8] As expected, triad states rely on more unique platforms than do states with just missiles and aircraft or with aircraft alone.

Nuclear portfolios seem to become more diversified with nuclear experience and with the development of new weapon systems, but there is still substantial variation within each category. This can be seen from the vertical lines in Figure 1 representing the range of platforms available to nuclear weapon states at that level of nuclear experience. To better understand this variation, we offer several statistical models of nuclear portfolio diversification, testing a number of factors behind a state's nuclear force structure decisions. In the remainder of this section, we describe the elements of our statistical model. Table 1 presents a summary of the hypotheses derived in the previous section, their predicted effect, and the explanatory variables used to test them.

Dependent Variable

To model the diversification of nuclear portfolios, we use as our dependent variable the number of unique nuclear platforms deployed by a state in a given year.[9] In choosing this dependent variable, we echo the substantial literature in economics and finance on diversification in investment portfolios, in which the number of different assets is commonly used as a proxy for diversification (Blume and Friend 1975; Goetzmann and Kumar 2008). Of course, this is an imperfect measure. A state can allocate weapons across each of its nuclear platforms in different ways, and a mere count of the number of unique weapon systems does not capture this dynamic. This measure also assumes equivalence between platforms that differ in their underlying capabilities. A portfolio consisting of a number of different weapon systems with roughly the same range, yield, and other characteristics is less diversified than a portfolio with the same number of platforms but wider variation between the capabilities of the platforms.

Still, the number of unique platforms may be the most relevant measure of diversification available because it comes closest to the actual political process by which nuclear officials and military planners make changes to nuclear force structure. States must make a conscious decision to create a new weapon system with a particular set of capabilities dictated by the state's strategic environment and its domestic constraints. The allocation of weapons across nuclear platforms, on the other hand, is a function of many factors outside the realm of politics, such as the technical reliability of the weapon system, deployment conditions, maintenance and upkeep, and the resulting service life of the platform. In the same way that the ups and downs of the stock market can quickly cause an allocation of stocks to slip away from an investor's target, the distribution of weapons may move independently from the intent of political leaders. A more reliable measure of an intended diversification scheme is the portfolio of stocks an investor explicitly chooses to buy. While it might be helpful to incorporate into the dependent variable a measure of the similarity of the different platforms a state employs, reducing the complexities of platform characteristics into a single index of similarity would inevitably leave out important dimensions of platform capabilities, biasing the result in ways that are difficult to anticipate.[10]

Our quantitative analysis employs two different versions of the dependent variable: the total number of unique nuclear platforms (tactical and strategic) and also the number of unique strategic platforms.[11] We use the strategic portfolio diversity version of the

Table 1. Nuclear Force Structure Hypotheses.

	Hypothesis	Expected effect on diversification	Measures
Domestic constraints	Resources	Increase	Real gross domestic product Military expenditures Nuclear capacity index Number of nuclear weapons
	Maturity	Increase	Log of years since becoming a nuclear state
Bureaucratic politics	Bureaucratic politics	Decrease	Air force personnel (percentage of military) Navy personnel (percentage of military)
Conventional threats	Conventional deterrence	Increase	Conventional threats Disputes over previous five years
	Opportunity costs	Decrease	Number of defense pacts
Nuclear rivalries	Arms race	Increase	Nuclear rival Rivals' number of nuclear weapons Rivals' number of unique platforms
	Rival distance	Increase	Minimum geographic distance to a nuclear rival
	Crisis	Increase	Disputes with rival over previous five years
	Arms control	Decrease	Arms control agreement signed within two years
Nuclear alliances	Complements	Decrease	Defense pact with nuclear state
	Mirror image	Increase	Allies' number of nuclear weapons Allies' number of unique platforms
	Ally distance	Increase	Minimum geographic distance to a nuclear ally

variable to assess the theories of nuclear force structure that derive from ideas of strategic nuclear deterrence. Existing studies of nuclear force structure deal almost exclusively with strategic nuclear weapons. Even the nuclear triad, an important method and framework for the diversification of force structures, contemplates largely strategic weapons. At the same time, to the extent that force structure considerations involve the deployment of tactical as well as strategic weapons, omitting tactical weapons risks biasing our results for those states with substantial tactical weapon portfolios.[12]

Explanatory Variables

We employ several variables to help understand how domestic constraints affect nuclear force structure. These variables capture a state's underlying economic, nuclear, and military capacity. We measure economic strength as the nuclear state's real gross domestic product (GDP) in a given year (Gleditsch 2002). Military resources are reflected in the Correlates of War project's military expenditure data (Singer 1988). Because new nuclear platforms often are designed specifically for a particular nuclear device, the ability of states to develop new warheads may drive platform diversification. We test this using Jo and Gartzke's (2007) seven-point composite index of latent nuclear capacity. We also include as an explanatory variable the total number of nuclear weapons held by the state in a given year (from the National Resources Defense Council with additions by the authors). To address the Maturity Hypothesis, we measure nuclear experience by adding one to the number of years since the state became a nuclear power and taking the log transformation. Nuclear acquisition dates are those commonly employed in the quantitative literature (Gartzke and Kroenig 2009).

The Bureaucratic Politics Hypothesis links the bureaucratic strength of an organization to the decisions of states to diversify their nuclear forces. As a proxy for bureaucratic strength, we collected data on the proportion of military personnel in the air force and the navy from the International Institute for Strategic Studies *Military Balance* and other country-specific sources.[13] We chose the share of military personnel strength over other measures, such as service budget size, because of the better availability of these data, because personnel numbers are less subject to measurement error, and because data on personnel are more responsive to events that alter the bureaucratic environment (such as war).

Turning to the Conventional Deterrence and Opportunity Cost Hypotheses, we measure a state's conventional threat environment in three ways. First, we calculate conventional threat by dividing the sum of rivals' Composite Index of National Capabilities CINC measures by the state's CINC score, adding one, and taking the log transformation (Jo and Gartzke 2007; Klein, Goertz, and Diehl 2006; Singer 1988). Second, we count the number of militarized international disputes in which a state participated over the preceding five years (Ghosn, Palmer, and Bremer 2004). Third, we tally the number of defense pacts to which a state belongs, based on data from the Correlates of War project (Gibler and Sarkees 2004). This last measure reflects the fact that a state with many alliance commitments faces a much more threatening strategic environment—and possibly different choices about nuclear force structure—than a state with no defense pacts.

Nuclear rivalries may be a major factor driving force structure decisions. To identify nuclear rivalries, we include a dichotomous variable that takes on the value of one when a rival has a nuclear weapon (Klein, Goertz, and Diehl 2006). We measure the nuclear capabilities of a rival as the number of its nuclear weapons and the diversification of its nuclear portfolio.[14] We test the Rival

Distance Hypothesis with the minimum geographic distance between the state and a nuclear rival (Weidmann, Kuse, and Gleditsch 2010). For states without nuclear rivals, we set this measure to zero—such states may have less need to project power over a long distance. To account for the potential for détente to flourish or for a mounting crisis between rivals to derail cooperation, we also include a count of the number of militarized international disputes a state has engaged in with its rival in the last five years (Ghosn, Palmer, and Bremer 2004). Finally, we address the effect of arms control treaties between the United States and Soviet Union with a dichotomous variable that takes on the value of one for these two states if any of the SALT I, SALT II, START I, or START II agreements had been signed in the previous two years.

Alliance dynamics are similarly important. We include a dichotomous variable for the presence of a defense pact with a nuclear state (Gibler and Sarkees 2004)—a commonly used proxy for a nuclear umbrella. As with nuclear rivals, we measure allied capability with the total number of nuclear weapons held by allies and the number of unique nuclear platforms they have deployed. We use the minimum geographic distance to a nuclear ally to test the Ally Distance Hypothesis.[15] Descriptive statistics for all variables are shown in Table 2.

Modeling Approach

We employ time-series cross-section data in which the unit of analysis is the country-year. To address likely serial correlation in our data as well as the fact that we use a count as our outcome variable, we employ a negative binomial generalized estimating equation (GEE) model with a first order autoregressive (AR1) working correlation structure (Zorn 2001).[16] Since nuclear platforms cannot be deployed overnight, we lag our explanatory variables by one year. A one-period lag reflects the assumption that diversification of nuclear portfolios does not respond immediately to changes in domestic constraints or the state's strategic environment but also does not require many years to respond. Here, we distinguish between the actual development of new platforms—which can take many years, even decades in some cases—and the decision to deploy or remove those platforms, which is likely to be much more responsive to the factors described above.

If the portfolio diversification of one state is related to that of others, as our hypotheses about nuclear rivals and nuclear allies suggest, then we may have spatial autocorrelation in our data. We account for this possibility by including in some model specifications explanatory variables that represent the level of portfolio diversification in rival and allied states. While we earlier justified these variables on theoretical grounds, they also serve as spatial lags in our models and help to correct for the spatial correlation of errors (Beck, Gleditsch, and Beardsley 2006).

While we adopt a pooled model, heterogeneity across states is a concern. It is clear that the United States and Russia represent a different breed of nuclear weapon

Table 2. Descriptive Statistics.

	Variable	*M*	*SD*	Minimum	Maximum
Dependent variable	Number of strategic nuclear platforms	11.16	13.16	1.00	57.00
	Number of nuclear platforms	6.11	3.89	1.00	18.00
Domestic constraints	Real gross domestic product	1.68	1.83	0.04	9.41
	Military expenditures	0.55	0.78	0.01	3.18
	Nuclear capacity	6.88	0.42	5.00	7.00
	Number of nuclear weapons	0.65	1.09	0.00	4.07
	Nuclear experience	2.82	0.91	0.00	4.01
Bureaucracy	Air force personnel (%)	0.20	0.09	0.03	0.36
	Navy personnel (%)	0.15	0.09	0.03	0.33
Conventional threat	Conventional threat	1.28	0.76	0.00	4.41
	Disputes (last five years)	14.51	9.29	0.00	38.00
	Number of defense pacts	14.08	15.64	0.00	53.00
Nuclear rivalries	Nuclear rival	0.74	0.44	0.00	1.00
	Rivals' number of nuclear weapons	1.55	1.69	0.00	6.40
	Rivals' portfolio diversification	23.51	22.29	0.00	69.00
	Rival's strategic portfolio diversification	9.88	8.35	0.00	25.00
	Distance to rival	0.03	0.08	0.00	0.82
	Disputes with nuclear rival (last five years)	4.71	6.21	0.00	26.00
	Arms control agreements	0.08	0.27	0.00	1.00
Nuclear alliances	Defense pact with nuclear state	0.47	0.50	0.00	1.00
	Allies' number of nuclear weapons	0.68	1.09	0.00	3.20
	Allies' portfolio diversification	7.07	8.48	0.00	25.00
	Allies' strategic portfolio diversification	5.20	6.48	0.00	21.00
	Distance to ally	0.07	0.16	0.00	0.41
Other	United States or Russia	0.35	0.48	0.00	1.00
	Cold War	0.77	0.42	0.00	1.00

state than the other members of the nuclear club. The two superpowers have many more nuclear weapons than the other nuclear states combined—in 1985, the US and Soviet arsenals accounted for 98 percent of global nuclear weapons—and a much wider range of strategic interests. Accordingly, we add to our models a dichotomous variable that takes on a value of one for the United States or Russia.

Cross-time heterogeneity is also a relevant issue. We employ a dichotomous variable that takes on a value of one for the duration of the Cold War, since different strategic dynamics were at play prior to 1991. As described earlier, we also consider accumulated experience with nuclear weapons using a logged count of the number of years a state has been a nuclear power.

Findings

Results of the negative binomial GEE analyses are shown in Table 3, with robust standard errors clustered by country. We report eight models in the analysis. The odd-numbered models use the count of *all* unique weapon platforms as the dependent variable.[17] Even-numbered models use the number of unique *strategic* weapon platforms as the dependent variable. Models 1 and 2 provide a baseline test of factors hypothesized to drive nuclear force structure. Models 3 and 4 examine the effect of nuclear rivalries, models 5 and 6 look at alliance dynamics, and models 7 and 8 combine these model specifications. Variables with positive coefficients are associated with increased nuclear portfolio diversification, while negative coefficients suggest the opposite.[18]

The Resource Hypothesis suggests that a lack of economic, military, or nuclear resources can lead to reduced portfolio diversification. Real GDP, our measure of economic resources, is negatively associated with portfolio diversification in models 1 and 3. Oddly, richer states seem less, not more, prone to diversify. The coefficients on military expenditures and nuclear capacity are positive and significant in most models, while the coefficient for a state's quantity of nuclear weapons, another proxy for nuclear capability, is positive and significant in all models. Perhaps these results should not surprise us. Any state that successfully developed nuclear weapons—a very expensive proposition—probably has sufficient economic resources to field new nuclear platforms. Limiting factors are more likely to be the technical hurdles posed by new platforms and willingness to devote available resources to the task. Clearly, nuclear capacity and weapon counts are better measures of these factors than a state's GDP; states with more latent nuclear capacity and more nuclear weapons tend to field more unique nuclear platforms than other states.

Capacity variables also demonstrate important substantive effects. Using models 7 and 8 as the basis for calculations, Table 4 reports the average impact on the number of unique nuclear weapon platforms of increasing the value of a variable from one standard deviation below its mean to one standard deviation above its mean (or from minimum to maximum for dichotomous variables). Table 4 only includes variables that are statistically significant at the $p < .10$ level. Moving from a moderately low number of nuclear weapons to a moderately high number, for example, yields an average increase of about two strategic platforms and about four platforms of all types, roughly one-third of the mean number of nuclear platforms in each case.

The Maturity Hypothesis implies that states increase the diversification of their nuclear portfolios over time. Examination of the time trend for the number of unique nuclear platforms seems to support this view (see Figure 1). Indeed, nuclear experience has a significant effect on the decisions of states to deploy new nuclear platforms in all models in the multivariate analysis. After controlling for other factors

Table 3. Analysis of Number of Unique Nuclear Platforms.

		Model 1 All platforms	Model 2 Strategic platforms	Model 3 All platforms	Model 4 Strategic platforms	Model 5 All platforms	Model 6 Strategic platforms	Model 7 All platforms	Model 8 Strategic platforms
Domestic constraints	Real Gross Domestic Product	−0.025 (0.008)**	−0.008 (0.019)	−0.036 (0.015)*	−0.010 (0.022)	−0.024 (0.028)	0.008 (0.028)	−0.022 (0.035)	0.008 (0.032)
	Military expenditures	0.056 (0.016)***	0.016 (0.010)^	0.042 (0.012)***	0.007 (0.011)	0.054 (0.021)**	0.017 (0.007)*	0.050 (0.013)***	0.008 (0.009)
	Nuclear capacity	0.191 (0.057)***	0.160 (0.122)	0.192 (0.070)**	0.146 (0.116)	0.226 (0.073)**	0.231 (0.096)*	0.205 (0.076)**	0.232 (0.092)*
	Number of nuclear weapons	0.238 (0.047)***	0.169 (0.047)***	0.226 (0.033)***	0.168 (0.037)***	0.237 (0.019)***	0.176 (0.044)***	0.236 (0.009)***	0.178 (0.034)***
	Nuclear experience	0.191 (0.071)**	0.218 (0.084)**	0.162 (0.062)**	0.203 (0.083)*	0.194 (0.079)*	0.196 (0.086)*	0.149 (0.068)*	0.180 (0.083)*
Bureaucracy	Air force personnel (%)	1.038 (0.420)*	0.653 (0.259)*	0.864 (0.369)*	0.651 (0.279)*	0.608 (0.191)**	0.471 (0.235)*	0.519 (0.181)**	0.458 (0.263)^
	Navy personnel (%)	−0.631 (0.227)**	−0.299 (0.433)	−0.473 (0.193)*	−0.159 (0.503)	−0.920 (0.227)***	−0.476 (0.409)	−0.802 (0.206)***	−0.343 (0.487)
Conventional threat	Conventional threat	0.000 (0.040)	0.020 (0.035)	−0.057 (0.058)	−0.024 (0.041)	−0.040 (0.040)	−0.005 (0.035)	−0.055 (0.054)	−0.043 (0.035)
	Disputes (last five years)	−0.007 (0.001)***	−0.007 (0.004)^	−0.007 (0.002)***	−0.007 (0.004)	−0.007 (0.002)***	−0.007 (0.004)	−0.008 (0.003)**	−0.007 (0.005)
	Number of defense pacts	−0.005 (0.002)*	−0.010 (0.003)**	−0.008 (0.003)**	−0.011 (0.005)*	−0.020 (0.005)***	−0.014 (0.004)**	−0.020 (0.005)***	−0.014 (0.005)**
Nuclear rivalries	Nuclear rival	−0.076 (0.074)	−0.113 (0.105)			0.002 (0.088)	−0.085 (0.111)		
	Rivals' number of nuclear weapons			0.111 (0.060)^	0.058 (0.034)^			0.158 (0.060)**	0.065 (0.034)^
	Rivals' portfolio diversification			−0.003 (0.003)				−0.006 (0.004)	
	Rival's strategic portfolio diversification				−0.005 (0.007)				−0.006 (0.008)
	Distance to rival			−0.109 (0.224)	−0.091 (0.122)			−0.215 (0.247)	−0.094 (0.112)
	Disputes with nuclear rival (last five years)	0.000 (0.006)	−0.003 (0.006)	0.000 (0.006)	−0.004 (0.006)	0.004 (0.006)	−0.002 (0.006)	0.005 (0.005)	−0.003 (0.006)
	Arms control agreements	0.010 (0.019)	0.001 (0.030)	0.009 (0.020)	0.003 (0.026)	0.009 (0.026)	0.006 (0.028)	0.012 (0.026)	0.008 (0.024)
Nuclear alliances	Defense pact with nuclear state	−0.096 (0.020)***	−0.050 (0.033)	−0.073 (0.025)**	−0.038 (0.036)				
	Allies' number of nuclear weapons					0.320 (0.066)***	0.155 (0.090)^	0.377 (0.075)***	0.177 (0.085)*
	Allies' portfolio diversification					−0.004 (0.006)		−0.005 (0.007)	
	Allies' strategic portfolio diversification						−0.003 (0.002)		−0.005 (0.003)
	Distance to ally					−0.497 (0.190)**	−0.044 (0.091)	−0.401 (0.158)*	−0.002 (0.118)
	United States or Russia	1.113 (0.481)*	0.581 (0.248)*	1.389 (0.455)**	0.562 (0.237)*	1.586 (0.170)***	0.737 (0.183)***	1.608 (0.150)***	0.722 (0.147)***
	Cold War	0.009 (0.038)	0.021 (0.053)	−0.020 (0.044)	0.003 (0.051)	0.039 (0.032)	0.010 (0.050)	−0.019 (0.029)	−0.015 (0.046)
	Constant	−0.269 (0.427)	−0.138 (0.775)	−0.300 (0.567)	−0.046 (0.767)	−0.540 (0.483)	−0.617 (0.624)	−0.332 (0.504)	−0.614 (0.626)
	N	274	274	274	274	274	274	274	274

Generalized estimating equation (GEE) negative binomial coefficients with robust standard errors, clustered by country, in parentheses. An AR1 working correlation structure is used. Explanatory variables are lagged one year.

^$p < .10$, *$p < .05$, **$p < .01$, ***$p < .001$.

Table 4. Substantive Effects of Statistically Significant Variables.

		Model 7 All platforms	Model 8 Strategic platforms
Domestic constraints	Military expenditures	0.58	
	Nuclear capacity	1.28	1.02
	Number of nuclear weapons	3.89	2.07
	Nuclear experience	2.04	1.74
Bureaucracy	Air force personnel (%)	0.67	0.42
	Navy personnel (%)	−1.02	
Conventional threat	Disputes (last five years)	−1.12	
	Number of defense pacts	−4.81	−2.41
Nuclear rivalries	Rivals' number of nuclear weapons	4.05	1.17
Nuclear alliances	Allies' number of nuclear weapons	6.34	2.07
	Distance to ally	−0.94	
	United States or Russia	17.10	4.36

Note: The average change in the number of unique nuclear platforms when the variable is increased from one standard deviation below its mean to one standard deviation above its mean (for continuous variables) or from its minimum to its maximum (for dichotomous variables). Values are included only for variables that were statistically significant at the $p < .10$ level for the model in question. See Table 2 for descriptive statistics for each of these variables.

that drive nuclear force structure, fledgling nuclear states do appear to have lower levels of portfolio diversification than do their more experienced counterparts.

We use data on the percentage of military personnel in the air force and navy as a proxy for the bureaucratic strength of those military branches to better understand the role of bureaucracy on nuclear force structure. The coefficient on the percentage of air force personnel is positive and significant in all models, while the navy personnel variable is negative and significant in the models that include tactical nuclear weapons.[19] Despite the apparent contradiction, these results seem generally consistent with the hypothesis. Nuclear bombers are present in all of the country-years in our data, so the air force, as the service responsible for the strategic power projection and control of the airborne nuclear deterrent, is never positioned to oppose the expansion of nuclear weapons into its sphere. More to the point, strategic bombing is a core mission of air forces around the globe. There is thus little reason for even highly bureaucratic air forces to oppose deployment of nuclear weapons on aircraft.

A strong navy, by contrast, may resist the diversification of nuclear portfolios that would include nuclear weapons at sea. The expansion of nuclear weapons to naval platforms represents a shift for the navy from its traditional mission, along with a shift in resources from its traditional procurement emphasis on new naval vessels. This dynamic may be particularly pronounced for nonstrategic naval nuclear weapons, such as antisubmarine helicopters, nuclear torpedoes, and tactical sea-launched cruise missiles, which represent many more unique platforms and may lack the prestige and substantial funding increases associated with strategic nuclear weapon systems.

We recognize that manpower strength is far from a perfect proxy for bureaucratic power. One concern is that measurement error biases our findings. Manpower estimates of Soviet forces during the Cold War, for example, often were based on counts of military equipment along with assumptions about how many individuals were needed to support particular military capabilities (Firth and Noren 1998). Given the well-known overestimation of Soviet airpower—the "bomber gap"—personnel numbers for the Soviet Union in particular may have been systematically overestimated. To assess the sensitivity of our results to such errors, we reestimated the models after shifting 50 percent of air force personnel to the navy (and vice versa). Neither change alters our results.

It is also possible that these measures proxy for overall military capability, rather than for bureaucratic heft. If modern navies are both leaner and more lethal than their less sophisticated contemporaries, for example, then our findings could stem from an association between naval modernization and portfolio diversification, not bureaucracy. There is no obvious correlation in our data, however, between naval personnel size and the introduction of at least one new naval capability, the SLBM. All but one state in our data set saw an increased naval share of military personnel at the time of its first deployment of an SLBM. While not definitive, this pattern gives us some reason to doubt that our bureaucratic politics measures are merely proxies for capability.

Our results support the Opportunity Costs Hypothesis. The military disputes variable is negative and significant in most models, and the coefficient on the count of a state's alliances is negative and significant in all models. Rather than spurring the creation of new platforms, as the Conventional Deterrence Hypothesis predicts, conventional insecurity weakens the impetus to diversify nuclear portfolios. While conventional deterrence may lead states to invest in particular types of nuclear forces, conventional threats do not drive overall portfolio diversification.

Turning to nuclear rivalries, we find some support for the Arms Race Hypothesis: the number of nuclear weapons deployed by a rival is significantly associated with an increase in diversification. The mere presence of a nuclear rival and the rival's portfolio diversification, however, do not affect nuclear force structure. We also find no support for the Rival Distance or Crisis Hypotheses; measures of rival geographic distance and recent disputes between rivals are not significant in our tests.[20]

Our analysis also casts doubt on the Arms Control Hypothesis. Arms control agreements seem to have no effect on the number of unique nuclear weapon systems fielded by states. This finding lends support to arms control critics that see such agreements as emphasizing particular nuclear forces, without reducing the number or variety of weapon systems overall. It may also be that the true effect of these agreements occurs too long after signing to be picked up by our choice of variables. It is conceivable, for example, that the arms control proxies in these models may be detecting the lingering buildup in nuclear forces that caused the arms control agreements to be negotiated in the first place, canceling out any effect from signing the actual agreements.

The presence and rough capabilities of a nuclear ally seem to affect nuclear force structure decisions. We find limited support for both the Complements and Mirror Image Hypotheses. The presence of a nuclear ally is associated with a drop in the average number of unique platforms that a state deploys, in models that include both tactical and strategic weapon systems. At the same time, the number of nuclear weapons held by allies is associated with an increase in the number of unique nuclear platforms; states do not appear to free ride off of the nuclear strength of an ally. A two standard deviation shift in the count of allied nuclear weapons leads to an average increase of about 2.1 strategic platforms and about 6.3 platforms of all types.

Nuclear alliances, however, do not lead to an exact mirror image of allied force structure; the number of allied nuclear platforms does not significantly impact the number of platforms a state holds itself. When it comes to making decisions about a state's own nuclear force structure, it may be that the number of nuclear weapons an ally possesses is a more salient measure of nuclear capability than is the overall diversification of its nuclear portfolio.

The minimum geographic distance to a nuclear ally is a statistically significant driver of reduced portfolio diversification in models that include both tactical and strategic weapons. This finding runs counter to the expectations of the Ally Distance Hypothesis. The result may reflect the particular population of states with no nuclear ally; these states receive an allied geographic distance of zero. When the models are repeated with those states excluded (reducing the sample from 274 to 128), the coefficient on the minimum distance to an ally becomes positive and significant.

Superpower status statistically and substantively increased portfolio diversification in all models. Just being a superpower increased the average number of strategic platforms by about four, with seventeen additional nuclear platforms of all types. The Cold War had a less pronounced effect on diversification; the dummy variable did not reach statistical significance in any model.

Conclusion

Decisions about nuclear force structure are complex and interrelated. States must deal with capacity constraints while responding to international threats, adjusting to rivals' arsenals, and coordinating with nuclear allies. Furthermore, decisions about nuclear force structure take place over multiple dimensions of state interest and across time. States do not just decide whether a new nuclear platform brings a needed capability; they also must weigh the diversification of the portfolio as a whole (both in isolation and in concert with their allies) and evaluate the mix of particular nuclear asset classes within the portfolio. The determinants of such complex decisions are themselves complex. Our empirical models suggest that the diversification of nuclear forces is limited by resource constraints and by the need to defend against conventional threats, but that diversification increases with nuclear experience and the nuclear capabilities of rivals and allies.

This work is an important first step in building a more nuanced understanding of what it means to be a nuclear power. It is clear that nuclear weapon states are not all the same and that difficult decisions about nuclear weapons and international conflict do not end with a state's first nuclear test. By highlighting key drivers of nuclear force structure, we hope to initiate a process where nuclear status is treated less as an on/off switch and more as a continuum of characteristics. This approach to nuclear security opens the door to new research into ways that nuclear weapons interact with state attributes and structural factors to influence global peace and security. Factors like nuclear doctrine, the attributes of nuclear forces, and changes in strategic thinking over time assume a new importance in this framework and may be fruitful avenues for future research.

Authors' Note

Earlier versions of this article were presented at the 2012 Midwest Political Science Association Annual Conference and the 2012 International Studies Association Annual Convention.

Acknowledgments

The authors thank Matthew Kroenig, Bryan Early, Dave Ohls, Rebecca Sanders, Adam Stulberg, two anonymous reviewers, and the other authors in this special issue for valuable comments. Adam Hogan and Nina Venuti provided helpful research assistance.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This project was supported by a research award from the Academic Senate at the University of California, San Diego, and by a Nuclear Science and Security Consortium faculty grant from the University of California's Institute on Global Conflict and Cooperation.

Supplemental Materials

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

Notes

1. Analysts use varying definitions of nuclear force structure, including everything from simple weapon counts to the entire command, control, and intelligence infrastructure behind these weapons. We see nuclear force structure broadly as describing the quality, quantity, and type of nuclear weapons and delivery platforms deployed by a state. At the same time, this definition excludes questions of nuclear doctrine and the larger national security apparatus.

2. Nuclear platforms are a means for delivering nuclear weapons, including aircraft and missiles (submarine launched or land based). We use the terms "nuclear platform," "delivery vehicle," and "weapon system" interchangeably.
3. The three legs of the nuclear triad are generally seen to include strategic bombers, intercontinental ballistic missiles, and submarine-launched ballistic missiles. Other, more esoteric, formulations exist: the US 2002 Nuclear Posture Review advances the idea of a "new triad" that consists of nuclear and nonnuclear offensive strike systems, active and passive defenses, and an enhanced defense infrastructure (US Department of Defense 2002). Here, we take the components of the nuclear triad to mean strategic air-, land-, and sea-based weapons of all ranges and capabilities.
4. Horowitz (2009) conducts robustness checks using variables meant to represent nuclear force structure—the number of nuclear weapons held by the state and whether it has deployed land-based missiles or SLBMs—but he does not report whether these force structure variables are significantly associated with the likelihood of conflict.
5. Our data set includes deployed nuclear platforms for the United States (1950–2000), the Soviet Union/Russia (1956–2000), the United Kingdom (1961–2000), France (1961–2000), China (1964–2000), Israel (1972–2000), South Africa (1982–1990), India (1988–2000), and Pakistan (1990–2000). In several cases, states deployed nuclear weapons before coverage begins in our data set. Reliable nuclear platform information was only available for the dates listed.
6. Please see the data appendix for a description of our data collection efforts and a complete list of sources used.
7. Our data on nuclear platforms include aircraft, land-based missiles, and submarine-launched missiles. We exclude nuclear gravity-type bombs and air-launched missiles, and count all nuclear artillery as a single platform.
8. The trend line representing nuclear triad states ultimately merges with the trend line for all nuclear states; the only states with fifty years of nuclear experience (the United States and Russia) have the nuclear triad.
9. Platforms need not be associated with different legs of the nuclear triad to be considered unique. For example, the US B1-B and the B2 bombers, though both are aircrafts, are treated as unique platforms. Variants of existing platforms are not treated as unique unless they have substantially different capabilities. We defer to source material as to whether delivery vehicles really represent different platforms. Please see the data appendix for more information.
10. We examine the diversity of nuclear portfolios in this article as a first step toward understanding the determinants of nuclear force structure. A complementary approach might examine the factors that lead states to deploy weapons with specific capabilities. We leave that effort for future research.
11. These measures are identical for Israel, South Africa, India, and Pakistan. All weapon systems in these states are considered strategic, both by our data sources and by the states themselves. There is some debate about whether China has deployed nonstrategic weapons; our primary models assume it has not, but we relax this assumption in robustness checks.

12. There exists no clear criteria by which to distinguish between strategic and tactical (also known as theater or nonstrategic) weapon systems (Kristensen 2012; Millar and Alexander 2003). We rely on our sources to best capture the prevailing view of analysts about particular weapon systems. Please see the data appendix for additional detail.
13. Missing values were imputed where data were available for some country-years but not others.
14. When the dependent variable is limited to strategic nuclear weapons, the rival diversification variable counts only unique strategic platforms deployed by the rival. The variable equals zero in the absence of a nuclear rival.
15. As with the nuclear rival measure, tactical platforms are included in the ally diversification measure when tactical platforms also are included in the dependent variable. These variables are set to zero in the absence of a nuclear ally.
16. We use Stata's xtgee command to estimate all models. In each case, we capture the α dispersion parameter from a standard negative binomial model and use that parameter for the negative binomial generalized estimating equation (GEE). The negative binomial model reduces to a Poisson when α is zero. In no case was α significantly different from zero, suggesting a Poisson model would also be suitable. Model convergence issues prevented using a Poisson GEE for each model, but results were nearly identical in those cases where both Poisson GEE and negative binomial GEE models could be estimated.
17. The models shown in Table 3 assume that China has not deployed tactical nuclear weapons, but analysts disagree as to whether this is so. We tested the sensitivity of this assumption for our results by adding arbitrary numbers of Chinese tactical weapon systems and reestimating the models. Although these tests do lead to some changes to the substantive and statistical significance of a few variables, they do not affect overall conclusions with respect to our hypotheses. Doubling China's platform count, for example, does not alter any results for models 7 and 8.
18. Countries with nuclear weapons have obviously experienced a previous stage of proliferation before choosing policies to develop particular force structures. Selection into nuclear status could be a source of concern. Phenomena like salary differential between genders are underestimated when differential incomes cause less skilled women to refrain from entering the job market (Heckman 1976). Three factors are worth considering here. First, force structure differs from income in that few countries proliferate (compared to the percentage of adults in the workforce) and one is consumption and the other compensation. We find it difficult to imagine that countries would proliferate if they could have eight nuclear weapon platforms, for example, but would stay in the nonnuclear club if they could only develop seven platforms. Second, and possibly more important, the likely result of this type of bias is to underestimate the effects reported here. By not modeling selection into nuclear status, we are reducing the likely range of values on key independent variables, to the degree that these variables also predict nuclear status. This is of course exactly the problem for Heckman in estimating wage differentials. Again, in the context of hypotheses about nuclear security, we may be less concerned about measuring the magnitude of effects than about being conservative in accepting hypothetical claims. Finally, and not unimportantly, modeling a two-stage selection process in the context of our estimator is highly problematic. We do not attempt this approach here.
19. We conducted a number of robustness checks on these variables. Making reasonable adjustments to the imputed values, but not dropping imputed observations, does not change our

results. However, excluding imputed values, which drop a total of eleven country-years from the analysis, causes the air force variable to lose statistical significance in model 2 and in models 4 through 8. Conversely, the navy variable gains statistical significance in model 6. Excluding the bureaucratic politics variables altogether does not substantially alter our findings for any of the other hypotheses.

20. Because there may be some overlap in the various rival measures, we reestimated the models while including only one rival measure at a time. This does not affect the results.

References

Allison, Graham T., and Frederic A. Morris. 1975. "Armaments and Arms Control: Exploring the Determinants of Military Weapons." *Daedalus* 104 (3): 99–129.

Asal, Victor, and Kyle Beardsley. 2007. "Proliferation and International Crisis Behavior." *Journal of Peace Research* 44 (2): 139–55.

Barkley, Daniel. 2008. "Ballistic Missile Proliferation: An Empirical Investigation." *Journal of Conflict Resolution* 52 (3): 455–73.

Bas, Muhammet A., and Andrew J. Coe. 2012. "Arms Diffusion and War." *Journal of Conflict Resolution* 56 (4): 651–74.

Beardsley, Kyle, and Victor Asal. 2009. "Winning with the Bomb." *Journal of Conflict Resolution* 53 (2): 278–301.

Beck, Nathaniel, Kristian Skrede Gleditsch, and Kyle Beardsley. 2006. "Space Is More Than Geography: Using Spatial Econometrics in the Study of Political Economy." *International Studies Quarterly* 50 (1): 27–44.

Bleek, Philipp, and Eric Lorber. 2014. "Security Guarantees and Allied Nuclear Proliferation." *Journal of Conflict Resolution* 58 (3): 429–54.

Blume, Marshall E., and Irwin Friend. 1975. "The Asset Structure of Individual Portfolios and Some Implications for Utility Functions." *The Journal of Finance* 30 (2): 585–603.

Brown, Robert L., and Jeffrey M. Kaplow. 2014. "Talking Peace, Making Weapons: IAEA Technical Cooperation and Nuclear Proliferation." *Journal of Conflict Resolution* 58 (3): 402–28.

Burt, Richard. 1978. "Reducing Strategic Arms at SALT: How Difficult, How Important?" *The Adelphi Papers* 18 (141): 4–14.

Chari, P. R. 2001. "Nuclear Restraint, Nuclear Risk Reduction, and the Security-Insecurity Paradox in South Asia." In *The Stability-Instability Paradox: Nuclear Weapons and Brinksmanship in South Asia*, edited by Michael Krepon and Chris Gagne, 15–36. Washington, DC: The Henry L. Stimson Center.

Chyba, Christopher F., and J. D. Crouch. 2009. "Understanding the U.S. Nuclear Weapons Policy Debate." *The Washington Quarterly* 32 (3): 21–36.

Cochran, Thomas B., William M. Arkin, and Milton M. Hoenig. 1984. *Nuclear Weapons Databook, Volume I: U.S. Nuclear Forces and Capabilities*. Cambridge, MA: Ballinger.

Cochran, Thomas B., William M. Arkin, Robert S. Norris, and Jeffrey I. Sands. 1989. *Nuclear Weapons Databook, Volume IV: Soviet Nuclear Weapons*. New York: Harper & Row, Ballinger.

Collina, Tom Z., and Daryl G. Kimbal. 2010. *Now More Than Ever: The Case for the Comprehensive Nuclear Test Ban Treaty*. Washington, DC: Arms Control Association.

Cortright, David, and Raimo Väyrynen. 2010. *Towards Nuclear Zero*. London, England: Routledge.

Enthoven, Alain C., and K. Wayne Smith. 1971. *How Much Is Enough?: Shaping the Defense Program, 1961-1969*. Santa Monica, CA: Rand.

Eyre, Dana P., and Mark C. Suchman. 1996. "Status, Norms and the Proliferation of Conventional Weapons: An Institutional Theory Approach." In *The Culture of National Security: Norms and Identity in World Politics*, edited by P. J. Katzenstein, 79–113. New York: Columbia University Press.

Firth, Noel E., and James H. Noren. 1998. *Soviet Defense Spending: A History of CIA Estimates, 1950-1990*. College Station: Texas A&M University Press.

Flory, Peter C. W. 2006. "Nuclear Exchange: Does Washington Really Have (or Want) Nuclear Primacy—Just the Facts." *Foreign Affairs* 85 (5): 149–50.

Fuhrmann, Matthew. 2009. "Spreading Temptation: Proliferation and Peaceful Nuclear Cooperation Agreements." *International Security* 34 (1): 7–41.

Fuhrmann, Matthew, and Todd S. Sechser. 2014. "Nuclear Strategy, Nonproliferation, and the Causes of Foreign Nuclear Deployments." *Journal of Conflict Resolution* 58 (3): 455–80.

Gartzke, Erik, and Dong-Joon Jo. 2009. "Bargaining, Nuclear Proliferation, and Interstate Disputes." *Journal of Conflict Resolution* 53 (2): 209–33.

Gartzke, Erik, and Matthew Kroenig. 2009. "A Strategic Approach to Nuclear Proliferation." *Journal of Conflict Resolution* 53 (2): 151–60.

Gartzke, Erik, and Matthew Kroenig. 2014. "Nuclear Posture, Nonproliferation Policy, and the Spread of Nuclear Weapons." *Journal of Conflict Resolution* 58 (3): 395–401.

Ghosn, Faten, Glenn Palmer, and Stuart A. Bremer. 2004. "The MID3 Data Set, 1993-2001: Procedures, Coding Rules, and Description." *Conflict Management and Peace Science* 21 (2): 133–54.

Gibler, Douglas M., and Meredith Reid Sarkees. 2004. "Measuring Alliances: The Correlates of War Formal Interstate Alliance Dataset, 1816-2000." *Journal of Peace Research* 41 (2): 211–22.

Gleditsch, Kristian Skrede. 2002. "Expanded Trade and GDP Data." *Journal of Conflict Resolution* 46 (5): 712–24.

Goetzmann, William N., and Alok Kumar. 2008. "Equity Portfolio Diversification." *Review of Finance* 12 (3): 433–63.

Halperin, Morton 1974. *Bureaucratic Politics and Foreign Policy*. Washington, DC: Brookings Institution.

Heckman, James J. 1976. "The Common Structure of Statistical Models of Truncation, Sample Selection and Limited Dependent Variables and a Simple Estimator for Such Models." *Annals of Economic and Social Measurement* 5 (4): 475–92.

Horowitz, Michael. 2009. "The Spread of Nuclear Weapons and International Conflict: Does Experience Matter?" *Journal of Conflict Resolution* 53 (2): 234–57.

Horowitz, Michael, and Neil Narang. 2014. Poor Man's Atomic Bomb? Exploring the Relationship between "Weapons of Mass Destruction". *Journal of Conflict Resolution* 58 (3): 509–35.

International Institute for Strategic Studies. 1963. *The Military Balance*. London: International Institute for Strategic Studies.

Jo, Dong-Joon, and Erik Gartzke. 2007. "Determinants of Nuclear Weapons Proliferation." *Journal of Conflict Resolution* 51 (1): 167–94.

Kak, Kapil. 1998. "Command and Control of Small Nuclear Arsenals." In *Nuclear India*, edited by Jasjit Singh. 268. New Delhi: Knowledge World.

Klein, James P., Gary Goertz, and Paul F. Diehl. 2006. "The New Rivalry Dataset: Procedures and Patterns." *Journal of Peace Research* 43 (3): 331–48.

Kristensen, Hans. 2012. "Non-strategic Nuclear Weapons." Federation of American Scientists, Special Report No. 3, Washington, DC.

Kroenig, Matthew. 2009. "Importing the Bomb: Sensitive Nuclear Assistance and Nuclear Proliferation." *Journal of Conflict Resolution* 53 (2): 161–80.

Kugler, Jacek, Abramo Fimo Kenneth Organski, and Daniel J. Fox. 1980. "Deterrence and the Arms Race: The Impotence of Power." *International Security* 4 (4): 105–38.

Lebow, Richard Ned, and Janice Gross Stein. 1995. "Deterrence and the Cold War." *Political Science Quarterly* 110 (2): 157–81.

Lieber, Keir A., and Daryl G. Press. 2006. "The Rise of US Nuclear Primacy." *Foreign Affairs* 85:42.

Lieber, Keir A., and Daryl G. Press. 2009. "The Nukes We Need: Preserving the American Deterrent." *Foreign Affairs* 88:39.

McCarthy, John F. 1976. "The Case for the B-1 Bomber." *International Security* 1 (2): 78–97.

Mettler, Simon A., and Dan Reiter. 2012. "Ballistic Missiles and International Conflict." *Journal of Conflict Resolution*.

Millar, Alistair, and Brian Alexander. 2003. *Tactical Nuclear Weapons: Emergent Threats in an Evolving Security Environment*. New York: Brassey's.

Narang, Vipin. 2010. "Posturing for Peace? Pakistan's Nuclear Postures and South Asian Stability." *International Security* 34 (3): 38–78.

Norris, Robert S., Andrew S. Burrows, and Richard W. Fieldhouse. 1994. *Nuclear Weapons Databook, Volume V: British, French, and Chinese Nuclear Weapons*. Boulder, CO: Westview Press.

Payne, Keith. 2006. "Nuclear Exchange: Does Washington Really Have (or Want) Nuclear Primacy—A Matter of Record." *Foreign Affairs* 85 (5): 150–52.

Perrow, Charles. 1986. "Economic Theories of Organization." *Theory and Society* 15 (1): 11–45.

Pifer, Steven. 2010. "New START: Good News for US Security." *Arms Control Today* 40 (4): 8–14.

Richardson, Lewis Fry. 1960. *Arms and Insecurity: A Mathematical Study of the Causes and Origins of War*. Richmond, VA: Boxwood Press.

Rosen, Stephen P. 1991. *Winning the Next War: Innovation and the Modern Military*. Ithaca, NY: Cornell University Press.

Sagan, Scott D. 1994. "The Perils of Proliferation: Organization Theory, Deterrence Theory, and the Spread of Nuclear Weapons." *International Security* 18 (4): 66–107.

Sagan, Scott D. 1996. "Why Do States Build Nuclear Weapons?: Three Models in Search of a Bomb." *International Security* 21 (3): 54–86.

Sagan, Scott D., and Kenneth N Waltz. 1993. *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*. Princeton: Princeton University Press.

Sagan, Scott D. 1995. *The Spread of Nuclear Weapons: A Debate*. New York: W. W. Norton.

Sapolsky, Harvey. 1972. *The Polaris System Development*. Cambridge, MA: Harvard University Press.

Sechser, Todd S., and Elizabeth N. Saunders. 2010. "The Army You Have: The Determinants of Military Mechanization, 1979-2001." *International Studies Quarterly* 54 (2): 481–511.

Singer, David J. 1988. "Reconstructing the Correlates of War Dataset on Material Capabilities of States, 1816-1985." *International Interactions* 14 (2): 115–32.

Singh, Sonali, and Christopher R. Way. 2004. "The Correlates of Nuclear Proliferation: A Quantitative Test." *Journal of Conflict Resolution* 48 (6): 859–85.

Snow, Donald M. 1979. "Current Nuclear Deterrence Thinking: An Overview and Review." *International Studies Quarterly* 23 (3): 445–86.

Solingen, Etel. 1994. "The Political Economy of Nuclear Restraint." *International Security* 19 (2): 126–69.

Stockholm International Peace Research Institute. 1968. *Annual Yearbook*. London: Oxford University Press.

Tago, Atsushi, and J. David Singer. 2011. "Predicting the Horizontal Proliferation of Nuclear Weapons." *Kobe University Law Review* 45:51–68.

US Air Force. *USAF Statistical Digests and Summaries*. Accessed July 1, 2013. http://www.afhso.af.mil/usafstatistics/.

US Department of Defense. 2002. *Nuclear Posture Review Report: Foreword*. Accessed April 12, 2012. http://www.defense.gov/news/jan2002/d20020109npr.pdf.

US Department of Defense. 2010. *Nuclear Posture Review Report*. Accessed April 12, 2012. http:// www.defense.gov/npr/docs/2010%20nuclear%20posture%20review%20report.pdf.

Waltz, Kenneth N. 1990. "Nuclear Myths and Political Realities." *American Political Science Review* 84 (3): 731–45.

Weidmann, Nils B., Doreen Kuse, and Kristian Skrede Gleditsch. 2010. "The Geography of the International System: The CShapes Dataset." *International Interactions* 36 (1): 86–106.

Younger, Stephen. 2000. *Nuclear Weapons in the Twenty-first Century*. LAUR-00-2850. Los Alamos, NM: Los Alamos National Laboratory.

Zorn, Christopher J. W. 2001. "Generalized Estimating Equation Models for Correlated Data: A Review with Applications." *American Journal of Political Science* 45 (2): 470–90.