WHAT CAUSES NUCLEAR WEAPONS PROLIFERATION AND RESTRAINT? THEORY, EMPIRICS, AND THE QUANTITATIVE TURN

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Draft Manuscript
Version: 27/10/2015

Feel free to cite but please do not quote without explicit authorization from the author.

ABSTRACT

The question of why some states proliferate while others do not has garnered considerable scholarly attention. In this review, I examine the large body of literature on the causes of the spread of nuclear weapons. I begin by considering studies on the technical capability of states to develop nuclear weapons (opportunity factors) and their motives for (not) doing so (willingness factors). Two important conclusions can be drawn from this review: 1) recent research has shown the importance of considering domestic politics, identity, norms, and the psychology of individual leaders to understand the proliferation process, in addition to the traditional realist notion that states desire in order to maximize their security; and 2) the proliferation puzzle is characterized by causal complexity, where no single theoretical account can sufficiently explain why a few states are tempted by nuclear weapons while most others are not.

In recent years, a new generation of proliferation scholars has turned to quantitative methods to test the large number of proliferation theories developed in earlier studies through the use of sophisticated quantitative methods. While such studies could provide valuable insight into the proliferation process, they are impaired by inconsistent findings. Moreover, I show that large-N studies of nuclear proliferation suffer from four shortcomings that call into question the reliability and validity of their findings.

Finally, I conclude by suggesting three avenues for future research, focusing on the non-proliferation regime, nuclear technology, and the systematic study of proliferation hypotheses beyond single or comparative case studies.

[1] An earlier version of this paper was presented at a PhD/postdoc seminar in Amsterdam in the fall of 2014. I thank the organizers (Liesbet Hooghe, Gary Marks, and Bart Bes) and the participants for useful comments. I am also grateful to Falk Ostermann, Barbara Vis, and Wolfgang Wagner for feedback and advice on previous versions.

INTRODUCTION

Decades after the 1945 Trinity test heralded the nuclear era, the real and imagined spread of nuclear weapons amongst states continues to command global attention. One only has to think of the international reactions to India's and Pakistan's nuclear tests in 1998 and various North Korean tests since 2006, the fuss over Iraq's alleged weapons of mass destruction (WMD) program that caused the 2003 invasion by a US-led coalition, and, most recently, the kerfuffle over the nature and intention of Iran's nuclear program. International non-proliferation efforts have overwhelmingly focused on preventing new states from joining the nuclear club by means of supply-side measures, that is, preventing the access to nuclear materials and technology by potential or suspected proliferators. Negotiations between Iran and the P5+1—or as the European powers would prefer it, the EU3+3[2]—have revolved around questions such as how many centrifuges are acceptable within the context of a peaceful program and to what percentage should Iran be allowed to enrich fissile materials. These technical questions are indeed important, if not crucial, as they determine whether a state has the ability to construct a bomb if it wants to as well as the timeframe in which it is capable of doing so. Yet, such policies overlook the reasons a state desires nuclear weapons in the first place. The lack of focus on motivations is chiefly caused by the prevailing belief in policymaking circles that the demand question is a simple one: states seek nuclear weapons for the security they provide vis-à-vis other states (Sagan 1996). Consequently, policy recommendations from this perspective usually amount to arms control, export controls, and confidence-building measures; in essence, not much different from the supply-side perspective.

The formulation of effective non-proliferation policy hinges upon a thorough understanding of the causes of proliferation efforts, which in turn has to rely on theory. Recognizing the immense destructive power and the military and political significance of nuclear weapons, scholars and experts

[2] The P5+1 or EU3+3 consists of China, France, Germany, Russia, the United Kingdom, and the United States.

have extended considerable attention over the years to the question: what causes the spread of nuclear weapons among states (for example, Rosecrance 1964; Dunn and Kahn 1976; Epstein 1977; Meyer 1984; Sagan 1996; Paul 2000; Solingen 2007)? Theorizing about the causes of nuclear proliferation and restraint has been particularly fertile since proliferation studies experienced a renewed scholarly interest after the Cold War drew down.

In the first part of this article I categorize and review the different explanations of nuclear proliferation and restraint. This review highlights the complex nature of the nuclear proliferation process, where different constellations of pressures, constraints, and possibilities produce similar outcomes in different cases (see also Ogilvie-White 1996; Sagan 1996). While existing proliferation theories highlight important aspects of the puzzle, and explain some cases better than others, none can provide a sufficient explanation on its own. In the second part of this article, I discuss the recent wave of quantitative studies that have attempted to test different proliferation theories across the universe of cases. I show that their findings have been inconclusive and examine their shortcomings. Finally, I conclude by presenting three avenues for future research on the causes of proliferation, focusing on the non-proliferation regime, nuclear technology, and improvements for the systematic empirical investigation of proliferation hypotheses beyond single and comparative case studies.

1. THEORIES OF NUCLEAR PROLIFERATION AND RESTRAINT

The literature on the causes of nuclear proliferation is usually divided between works related to the "supply-side," that is, the technological, industrial, and economic capability of states to develop nuclear weapons, and works on the "demand-side," that is, the motives of actors for developing nuclear weapons. Jo and Gartzke (2007a) provide a convenient extension to this categorization by making use of the notion of opportunity and willingness factors. Nuclear opportunity refers to "the total set of environmental constraints and possibilities" a state is confronted with as regards the development of a nuclear weapon (Most and Starr 1989:23; Siverson and Starr 1990:84). In short, it is about a state's ability to develop a nuclear weapon (the supply-side). Nuclear willingness pertains to "a decision maker's calculations of advantage and disadvantage, cost and benefit, considered on both conscious and unconscious levels" of the utility of nuclear weapons (Siverson and Starr 1990:48). In other words, it refers to a set of factors that either motivate or dissuade a state from making the *choice* to develop a nuclear weapon (the demand-side). Opportunity and willingness, therefore, are "jointly necessary conditions" for explaining proliferation behavior (Most and Starr 1989:23–46; Russett, Starr, and Kinsella 2009:23).

Nuclear Opportunity: the Ability Question

National Nuclear Capability

While a few states have tried, unsuccessfully, to purchase operational nuclear weapons or inherited them, to develop a nuclear weapon a state has to overcome significant technical, scientific and financial hurdles.[3] In the 1960s, the general expectation among policymakers was that as knowledge of nuclear technology developed and the technological capability to construct nuclear weapons spread among states, more of them would soon join the nuclear club. In 1963, President Kennedy forecast: "I see the possibility in the 1970s of the president of the United States having to face a world in which 15 or 20 or 25 nations may have these weapons" (as quoted in Test Ban: Choice Between Risks 1963:37). It is then surprising that there is such a gap between the number of states that are technically capable of developing nuclear weapons—a few dozen at present—and the small number of actual nuclear-weapons states (NWS). The underlying assumption that more states

[3] On attempts to purchase operational weapons see, for instance, Sinai (1997:98) on Libya, Walsh (1997:1–5) on Australia, and Rublee (2006:559) on Egypt.

have become capable of building nuclear weapons raises the issue of how to define and measure a state's technical capabilities.

In a pioneering book, Meyer (1984) developed a model to assess a state's latent capability to build a bomb within six years or less by measuring a set of industrial, scientific, and technical achievements that could be placed at the service of a nuclear weapons program. Based on these indicators, he found that thirty-six states had at one point or another possessed the latent capability to build a bomb between 1940 and 1982. Stoll (1996) updated Meyer's dataset until 1992 but dropped the requirement for indigenous uranium deposits from 1970 onwards, arguing that all states had access to uranium on the world market. As a result, Stoll found that 48 states possessed a latent capability in 1992. Jo and Gartzke (2007a) constructed their own latent capability dataset for the years 1938-2002, broadly following Meyer's and Stoll's coding rules but dropping three of Meyer's indicators (national mining activity, coal coking/distilling petroleum, and cement production) because they are too easily available to be thresholds. More significantly, they reintroduced the uranium deposit prerequisite but extended it to either having uranium deposits or having produced uranium already (Jo and Gartzke 2007b:7). They found that 45 states possessed a full latent nuclear capability in 2001.

Despite their conceptual appeal, these models of nuclear capability suffer from several shortcomings. Frequently, scholars resort to measuring that which is easily measured, rather than constructing original datasets that adequately capture the concepts they are ultimately concerned with (Sagan 2010). Scholars interested in measuring nuclear weaponization capability (for instance, the ability to design and fabricate high-explosive components and triggers that set off the nuclear core) could construct datasets on arms manufacturing experience and expertise, rather than rely on crude proxy measures such as automobile and television manufacturing that say little about a state's ability to successfully build a nuclear weapon as Meyer, Stoll, and Jo/Gartzke do.[4] Moreover, their coding often incorporates crucial assumptions—such as Stoll's premise that all states have access to fissile materials—that have a strong, though mostly uncredited, impact on assessments of latent nuclear capability. By diverting attention from the acquisition of nuclear materials, these studies have overestimated the number of states that possess the capability to make a nuclear weapon.

Upon further inspection of Jo and Gartzke's dataset, Sagan (2011:229f.) discovered significant inconsistencies with existing knowledge of the nuclear capabilities of several states. Jo and Gartzke's coding rules, for instance, led to the conclusion that South Africa was not capable of building a nuclear weapon in 2001 (because it lacked nitric acid production capability and chemical engineers), even though it had produced six nuclear weapons in the 1980s and still possessed between 450 and 600 kilograms of highly enriched uranium. On the other hand, Egypt, with only two research reactors, was considered to have a higher degree of nuclear latency than South Africa. The use of proxy measures also resulted in Trinidad and Tobago being assessed as having a higher degree of nuclear latency in 2001 than North Korea, which was only five years away from conducting its first nuclear test. Such inconsistencies throw serious doubt on the accuracy of these nuclear capability models.

Perhaps the most significant shortcoming in these nuclear latency datasets is the lack of attention to enrichment and reprocessing facilities (ENR). These are the plants that produce the necessary fissile materials for nuclear energy and nuclear weapons purposes. Meyer, Stoll, and Jo/Gartzke use proxy measures, such as the operation of a research reactor for a minimum of three years, instead of ascertaining whether a state operates plants that are able to produce plutonium or weapons-grade uranium. Again, such practices lead to wildly inaccurate outcomes. Countries that operate research reactors but lack advanced nuclear facilities—such as Thailand, Peru, and

[4] This point is further explored below (see p. 24).

Colombia—would attain the highest possible score on Jo and Gartzke's (2007a) latent capability index in 2001 (Fuhrmann and Tkach 2015:3f.). More explicitly, these countries lacked the ability to produce the fissile materials needed for nuclear weapons and therefore clearly fall short of having the latent capability to do so.

While experts can debate how to best specify techno-centric models of nuclear capability, they overlook and fail to explain a key trend in the spread of nuclear weapons. Not only have fewer states acquired nuclear weapons than expected—despite the spread of nuclear know-how and materials—but states have also come to need more time to develop a bomb. As Hymans (2012b:45f.) notes, the average time required for successful projects until 1970 was roughly seven years, whereas projects after 1970 have taken seventeen years on average until completion. Some credit for achieving this may be given to the non-proliferation regime and its system of export controls, safeguards, and inspections, though these measures only became effective in the 1990s. More importantly, timelines to the bomb have increased considerably because most post-1970 nuclear aspirants have been developing countries that have had trouble establishing high-quality state bureaucracies that can successfully manage nuclear weapons projects (Hymans 2008, 2012a, 2012b). Because management of nuclear projects in such states is often authoritarian and coercive, and decisions are made by meddling politicians instead of scientists, they often botch even the simplest steps of the process.

Nuclear Assistance

Following the neglect of the acquisition of nuclear materials in earlier scholarship, a number of recent studies have focused on the link between nuclear assistance and proliferation. Kroenig (2009b) argues that states that receive sensitive foreign nuclear assistance are more likely to acquire nuclear weapons.[5] He finds empirical support for the hypothesis that sensitive nuclear assistance is positively correlated to weapons acquisition. Surprisingly, he also finds that non-sensitive or civilian nuclear assistance is negatively correlated with acquisition.

The conclusion that states that receive help in building a bomb are more likely to acquire a bomb is predictable. More interesting is Kroenig's (2009a) examination of the question why advanced nuclear states provide sensitive assistance to non-nuclear-weapon states (NNWS), contributing to the spread of nuclear weapons. Contrary to earlier works that argue that economic incentives lead states to provide sensitive nuclear assistance, he hypothesizes that political and security considerations ultimately drive this decision. States are less likely to provide sensitive assistance to states over which they can project conventional military power, because opposing nuclear weapons will reduce the effectiveness of their conventional military power and coercive diplomacy. And, they will be more likely to provide assistance to states with which they share a common enemy or when they themselves are less vulnerable to superpower pressure.[6]

Contrary to Kroenig, Fuhrmann (2009a) contends that the spread of all types of nuclear technology, not only the sensitive kind, increases the likelihood of proliferation. He argues that civilian assistance and weapons proliferation are causally linked because of the ever-present dual-use character of civilian nuclear technology and knowledge. Civilian assistance not only leads to the supply of technology and components that can be used for nuclear power but also establishes an "indigenous base of knowledge" that can be directed towards a weapons program (Fuhrmann 2009a:39). Fuhrmann finds evidence that peaceful nuclear assistance contributes to the likelihood of nuclear weapons program onset and the acquisition of nuclear weapons. The data, for instance,

[5] His definition of sensitive assistance includes receiving information on the design and construction of nuclear weapons, receiving large amounts of weapons-grade fissile materials, or assistance in the construction of facilities for uranium-enrichment or plutonium-reprocessing that could be used to produce weapons-grade fissile materials.
[6] The common enemy hypothesis is also confirmed in the case of civilian assistance by Fuhrmann (2009b).

show that eighty percent of the states that initiated weapons programs did so after signing a nuclear cooperation agreement (NCA) with another state. The four countries that started weapons programs without receiving civilian assistance (France, the Soviet Union, the United Kingdom, and the United States) did so at a time when formal civilian nuclear cooperation did not exist yet.[7] The study's key insight is that states might at first accumulate civilian technologies for peaceful purposes but then bow to the temptation to acquire nuclear weapons, particularly when crises or security threats arise.

While Fuhrmann's findings are compelling, they are not exempt from criticism (see Sagan 2011:232). He, for instance, does not account for the possibility that a state's interest in nuclear weapons may have, in part, triggered its decision to seek civilian assistance. Assistance can, thus, be the consequence of a state's proliferation intention rather than the cause of its proliferation behavior. Nonetheless, Fuhrmann's findings are a salient critique of the notion that civilian assistance could serve as an effective arms control policy, as has been the widespread belief ever since President Eisenhower's 1953 "Atoms for Peace" speech before the UN General Assembly.[8] On the contrary, his analysis "reveals that 'atoms for peace' policies have, on average, facilitated—not constrained—nuclear proliferation. Atoms for peace become atoms for war" (Fuhrmann 2009a:40).

Technological Determinism

In the 1960s and 1970s, scholars hypothesized that the availability of nuclear technology and knowhow leads to gradual progress towards the development of a nuclear weapons capability well before a political decision to acquire a weapon is made (Rosecrance 1964; Dunn and Kahn 1976:5).

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[7] Of course they did enjoy (sensitive) international assistance in the form of "explicit collaboration, shared expertise, blueprints, shortcuts, and material assistance (such as heavy water and nuclear fuel)," as well as the efforts of émigré scientists and information obtained through espionage (Abraham 2010:51f.).

[8] 15 years later this belief was formalized in articles IV and V of the Treaty on the Non-Proliferation of Nuclear Weapons (NPT).

According to this view, "technologies change following their own internal logic or the careers, institutional and financial interests of their developers" (MacKenzie 1990:122). A more radical version of this technological determinist perspective holds that some technologies become autonomous and give rise to their own development, whereas human agency is powerless to restrain it (Roland 2010:445). While it is true that humans ultimately design and manufacture nuclear weapons, the determinist argument is that technological momentum and the desire for nuclear weapons are so ubiquitous that decision makers are "pulled along" (Lavoy 1993:194f.).

From this perspective, the proliferation problem is the consequence of the availability of nuclear technology and prospective proliferators are seen as "a mass of 'Nth' countries" (Betts 1993:105f.). Technology is the driving force behind nuclear proliferation and "governments 'decide' to go nuclear because the technology is available, thereby making technical/financial costs manageable and the opportunity irresistible" (Meyer 1984:9). The technological determinist view helps to account for the dogmatic efforts to impose strict supply-side controls on nuclear proliferation since the establishment of the Treaty on the Non-Proliferation of Nuclear Weapons (NPT).

Yet, the proposition that all states with a latent nuclear capability will eventually acquire nuclear weapons lacks empirical basis and is a logic that is borne out of a "policy mindset that abhors uncertainty and requires, to be taken seriously, the presentation of the worst case as most likely" (Abraham 2010:54). The focus that earlier studies laid on near-nuclear states such as India and Germany—states with advanced nuclear infrastructures that brought them close to weapons acquisition—biased the debate in favor of the technological imperative hypothesis, because these states deliberately developed their nuclear infrastructure to have a weapons capability (Hymans 2010:19). In order to overcome this endogeneity problem, Meyer developed the aforementioned latent capability model that measured a state's ability to build a bomb in six years or less, in lieu of estimating a state's current level of nuclear technology. His model showed that by 1963 (the year

President Kennedy famously warned that 15 to 25 states might acquire nuclear weapons in ten to twelve years), in fact 14 states had already achieved the ability to build a bomb in six years or less (Meyer 1984:41, table 2). Yet, if so many states that have had the capability to build a nuclear weapon for a long time have not done so, the technological imperative must not be deterministic at all (cf. Betts 1993; Lavoy 1993). On the contrary, while technical capability is a necessary condition for developing nuclear weapons, it is not sufficient by itself. To fully comprehend the proliferation process one must study the factors that motivate or dissuade actors from pursuing nuclear weapons.

Nuclear Willingness: the Demand Question

National Security

Security considerations are the most frequently cited explanation of why states desire to acquire nuclear weapons. This point of view, associated with the (structural) realist school of International Relations (IR), rests on the assumption that an anarchic international system, characterized by a logic of self-help, leads rational states to seek to maximize their security in a competitive environment with limited resources (Waltz 1979). Consequently, a state will seek to deter a nuclear-armed foe either by developing its own nuclear capability or by allying itself with another nuclear power (see, for instance, Epstein 1977; Mearsheimer 1990; Betts 1993; Frankel 1993; Sagan 1996; Waltz 2012).[9] Likewise, weaker states may pursue such weapons to balance against a more powerful and/or

[9] The quest for nuclear weapons to protect against a nuclear-armed foe is arguably the most parsimonious explanation for the proliferation chain reaction in the immediate period after World War II. When a state develops a nuclear weapon to balance against a (nuclear armed) rival it creates a similar threat to its neighbors, instigating the need for these states to develop their own nuclear programs. For more on the effect of security guarantees on dampening nuclear ambitions in realist thought see, for instance, Frankel (1993) and Thayer (1995).

capable conventionally-armed rival (Dunn and Kahn 1976:96; Waltz 1981; Quester 1988; Lavoy 1993:195f.).[10]

Despite the appeal and parsimony of the security argument, realism tends to overpredict proliferation. While many states that have sought a nuclear deterrent have indeed faced external security threats, numerous states facing nuclear rivals—Japan, South Korea, Brazil, and Argentina, to name but a few—have not given into temptation. Moreover, different states have followed different paths despite similar security conditions, reflecting the indeterminate nature of the realist security model. Japan and South Korea, for instance, relied on US security guarantees, Israel (a nuclear possessor) maintained a nuclear policy of "deliberate ambiguity" outside the non-proliferation regime, and Brazil and Argentina gave up their nuclear ambitions to prevent a regional arms race (Solingen 2007; Paul 2000).[11] While realism provides appealing and valuable insights about proliferation dynamics, its tendency to explain inconsistencies through mechanisms unrelated to self-help underscores the necessity of alternative accounts of nuclear decision-making and behavior (Legro and Moravcsik 1999; Solingen 2007; Rublee 2009).

Aside from empirical inconsistencies and the open-ended nature of the realist self-help logic, the retrospective quest to find evidence of security considerations in nuclear decision-making represents a third flaw in this line of research. As Sagan (1996:63) observes, a popular research strategy is to take note of a nuclear weapons decisions or a case of restraint and then work back in time, trying to

[10] The Israeli weapons program is the most compelling case of nuclear acquisition in response to a conventional threat (posed by its Arab neighbors). Lavoy (1993:196) argues that Pakistan initiated its nuclear program not because it was concerned about India's nuclear arsenal but its conventional military advantage.

[11] While most advocates of the security model examine cases of proliferation, Paul (2000) addresses the paradoxical instances where technologically capable or potentially capable states choose not to acquire a weapon and states that choose to give up nuclear weapons they already possess. Though Paul acknowledges the traditional realist contention that the possession of nuclear weapons deters potential adversaries and increases power and prestige, he points out that acquisition also threatens to destabilize relations with neighboring states. Consequently, a prudential calculation by states of their interest in power and security—essentially being sensitive to the security dilemma—lies at the heart of a decision to show nuclear restraint. On the other hand, states that are embroiled in a protracted conflict or enduring rivalry with an existing or emerging NWS have the greatest incentive to proliferate, particularly when lacking a nuclear guarantee from an ally.

find the security threat that "must" have caused that decision. This is problematic insofar as security model explanations rely on, first, statements by key decision makers who have an interest in portraying their choices as serving the national interest and, second, a "correlation in time" between the occurrence of a security threat and a proliferation decision, which is often incongruent with the historical record.[12]

Non-proliferation Norms and Law

Considering that nuclear alarmists have been predicting a rapid acceleration in the spread of nuclear weapons since the 1960s, it is striking that only nine states currently possess them. With the establishment of a, now near universal, nuclear non-proliferation regime, a number of scholars have sought to explain widespread nuclear abstention by looking at the regime and its constituent norms, rules, and agreements. These studies can be broadly characterized as realist, neoliberal institutionalist, and social constructivist approaches to international law and norms.[13]

The realist view of international law has many varieties but is at its core characterized by a cynical attitude. The core realist assumption is that international law has no explanatory power or independent meaning but rather is epiphenomenal, a reflection of the interests of powerful states. To put it another way, realist "orientations are resistant to the contention that principles, norms, rules, and decision-making procedures have a significant impact on outcomes and behavior" (Krasner 1982:190). The most skeptical argument regarding the irrelevance of the NPT is made by Betts (2000:69): "*If the NPT or CTBT themselves prevent proliferation, one should be able to name at least one specific*

[12] The realist logic, for instance, dictates that following China's 1964 nuclear test (and the 1962 Sino-Indian War), India had to develop its own deterrent, culminating in the 1974 "peaceful nuclear explosion." Yet, the credibility of the realist account is undermined for two reasons: 1) India did not initiate a crash weapons effort in response to China's test, despite being able to produce enough weapons-grade material annually for at least one bomb from mid-1964 onwards; and, 2) it did not make any consistent efforts to seek security guarantees from other nuclear powers (Sagan 1996:65; Abraham 1998:123–27; Perkovich 1999).

[13] Arend (1997:n. 7) explains that IR scholars frequently avoid explicit references to international law and legal rules, but often use a variety of other terms to discuss them, such as "norms," "rules," and "decision-making procedures."

country that would have sought nuclear weapons or tested them, but refrained from doing so, or was stopped, because of either treaty. None comes to mind" [emphasis in original]. However, this argument is flawed because it overlooks the many states that were considered potential proliferators in the past that have ultimately abstained from proliferating, such as West-Germany, Egypt, and Sweden to name but a few (Sagan 2011:237).

Another realist approach views the NPT as a codification of a double-standard or even a way to manage hypocrisy (Paul 2000:29f.; Sagan 2011). Initially, the chief backers of the Treaty were the NWSs and the NNWSs that had little or no chance of ever going nuclear, for they had a shared interest in preventing major industrialized states, such as Japan and West Germany, and Third World countries, like India and Brazil, from developing a weapons capability (Epstein 1977:17). That the NPT was opened up for universal signature was merely a way to make the implications politically acceptable for these states (Swango 2009). Many contemporary realists, nonetheless, believe that international law "may define credible commitments and reduce transaction costs in international negotiations" (Steinberg 2002:261). International regimes play an important role in coordinating relations between states, though they may only be possible on matters of security if they are supported by great powers who prefer a regulated environment rather than one in which states behave individualistically (Jervis 1982:360).

Neoliberal institutionalism paints a more optimistic picture of international law and the non-proliferation regime. Like their realist counterparts they do not believe that international law and institutions change the identities and interests of actors, and with that their fundamental desire for nuclear weapons. They, however, concentrate on the role that international institutions play in easing the security dilemma by providing information about the intentions and capabilities of others and by monitoring and even enforcing compliance (Keohane 1984; Solingen 2007). According to institutionalist theory, the NPT addresses two pressing collective action problems (Smith 1987; Dai

2007). First, the NWSs find it useful to refrain from providing nuclear weapons to other states, provided that other NWSs do the same (Article I NPT). Second, the NNWSs find it useful to refrain from pursuing nuclear weapons, granted that other NNWSs likewise refrain (Article II). In return, they are guaranteed access to civilian nuclear technology and participation in nuclear trade (Articles IV and V), while the NWSs make a nominal commitment to pursue disarmament (Article VI). As a solution to these two problems, the NPT (Article III) provides for a centralized compliance monitoring system under auspices of the International Atomic Energy Agency (IAEA). According to Dai (2007:52f.), states are interested in high-quality information on compliance of other states, because they view proliferation as a top concern. Given the secrecy that surrounds nuclear activities, states are unlikely to obtain the information they require from a low-cost, decentralized monitoring system, as is the case with many human rights regimes. Therefore, states gladly invest in the IAEA's centralized monitoring system.

Social constructivist scholarship refers to law on a more regular basis than realist and institutionalist literature (Arend 1997; see for instance Kratochwil 1989 and Onuf 2013). Constructivists argue that social forces such as ideas, rules, and norms have an impact on states' interests and identities. Such interests and identities can undergo change through a process of social interaction. Joining a legal regime not only constrains the behavior of states, but the very act of participation influences the way states view themselves and how they define their interests. Thus, legal regimes do not only have a regulative effect—meaning that they constrain existing activities—but also a constitutive effect through the construction of roles and identities (Arend 1997:132ff.; Tannenwald 1999, 2007).

Following the advent of the atomic age, the acquisition of nuclear weapons was considered legitimate and even embodied membership in an "elite club" of prestigious states (Sagan 1996:76; Arend 1997:139). Rublee (2009:202) posits that over time the international social environment, strengthened by the non-proliferation regime, has created normative pressures on states' conceptions of the value of nuclear weapons: "nuclear proliferation became more costly—economically, technically, and diplomatically—whereas nuclear nonproliferation became more rewarding." Tannenwald (1999, 2007) employs process tracing to show how a particularly forceful nuclear non-*use* norm—that is, a 'nuclear taboo'—emerged after World War II, over time leading to the prevailing view that the use of nuclear weapons is unacceptable.[14] This stigmatization was institutionalized in the NPT and the broader non-*proliferation* regime from the 1960s onwards. In turn, accepting and complying with the norms defining nuclear weapons as illegitimate bolsters the "identity of states and their status as legitimate members of the international community" (Price and Tannenwald 1996:142).

Status and Prestige

While non-proliferation norms can prove to be a strong counterweight to the spread of nuclear weapons, a different set of normative forces may incentivize it as nuclear weapons come to be thought of as symbols of scientific and technological development. Likewise, they can be symbols of regional or international prominence, particularly when states suffer from a perceived status inconsistency. Sagan (1996:74) argues that from this perspective, "military organizations and their weapons can […] be envisioned as serving functions similar to those of flags, airlines, and Olympic teams: they are part of what modern states believe they have to possess to be legitimate, modern states." But, why are some acts of proliferation considered prestigious, while others are stigmatized? Sagan (1996:76) argues that the answer can be found in the non-proliferation regime, as it "appears to have shifted the norm concerning what acts grant prestige and legitimacy from the 1960s notion

[14] Following Tannenwald's work, Press, Sagan, and Valentino (2013) conducted a survey experiment to evaluate American public attitudes regarding nuclear use. They report that Americans have only a weak aversion to nuclear use, seemingly contradicting a "nuclear taboo."

of joining the 'nuclear club' to the 1990s concept of joining 'the club of nations adhering to the NPT'." Sagan illustrates this point by contrasting the French decision to conduct its 1960 nuclear test with Ukraine's decision to give up its inherited stockpile of Soviet-era nuclear weapons and join the NPT as a NNWS in the 1990s.

Domestic and Bureaucratic Politics

Sagan's (1996) domestic politics model emphasizes the role of political actors or bureaucratic coalitions that form to support or oppose nuclear weapons out of parochial interests. This approach opens up the black box of decision-making by highlighting bureaucratic actors—such as the civilian and state-run nuclear energy establishment, important units in the military apparatus, and influential politicians—that "create the conditions that favor weapons acquisition by encouraging extreme perceptions of foreign threats, promoting supportive politicians, and actively lobbying for increased defense spending" (Sagan 1996:64). A related perspective stresses the importance of nuclear myths and mythmakers. It holds that, despite the uncertainty surrounding nuclear weapons acquisition and its political and military consequences, a state is likely to proliferate when elites highlight the state's insecurity and poor reputation by promoting the myth that nuclear weapons provide security, prestige, and political power (Lavoy 1993). According to the domestic politics model, external security threats are not the chief antecedent of proliferation; they are rather "windows of opportunity through which parochial interests can jump" (Sagan 1996:65). Hence, it is plausible that liberalization and the spread of democracy constrain the power and autonomy of bureaucratic elites who favor weapons acquisition for parochial reasons (Sagan 1996; Barletta 1999).

Solingen (1994, 2007) offers a neoliberal take on the domestic causes of nuclear proliferation and restraint. Her contention is that leaders or domestic coalitions who pursue economic liberalization and integration in the world economy are more likely to abstain from developing nuclear weapons because their political survival relies on economic growth through foreign investment and exports. Nuclear abstention or reversal enforces the status of such coalitions with major powers on whom they depend for support—chiefly the system leader, the United States—and the institutions that are involved with managing international economic relations (such as the International Monetary Fund and the World Bank). In contrast, leaders or ruling coalitions that are inward-looking, nationalist, and radical-confessional, will be more inclined to pursue nuclear weapons.

Solingen (2007) presents nine extensive case studies from countries in the Middle East and East Asia to support the thesis that domestic actors consider a broader set of factors than the state's security environment and relative power position when deciding on a nuclear stance. She, for instance, unorthodoxly argues that a nuclear guarantee—a realist explanation for nuclear restraint—was not the key explanatory variable for Japan's nuclear abstention—which is surprising considering its precarious security environment and its technological prowess. The nuclear alliance rather was a critical component of the Japanese leadership's model of political survival, which rested on export-driven economic growth and domestic stability, while avoiding economically and politically costly military policies.

The principal shortcoming in Solingen's theory is the selective inclusion (or exclusion) of ideas and norms-based components without acknowledging them. In her treatment of liberalizing coalitions, changes in nuclear policy are caused exclusively by the economic interests of domestic coalitions.[15] On the other hand, Solingen argues that inward-looking or radical-confessional nuclear aspirants are influenced by economic as well as ideational considerations. The material basis of inward-looking coalitions can be found in powerful import-substituting and state-based industrial

[15] Yet, as Rublee (2009:12) points out, such liberalizing (and often democratizing) regimes not only sought membership in the Western "club" for access to foreign markets but also for status and social reasons.

interests, while some inward-looking coalitions—particularly those driven by religious or ideological components—thrive on "popular resentment over adjustment policies they regard as externally-imposed, reliance on foreign investment, and the 'Western' principles and norms embodied in most international regimes" (Solingen 1994:140).

While the difference between material and ideational bases of political action is acknowledged, albeit passingly, in Solingen's 1994 article, her 2007 book fully subsumes any ideational component under the materialist header of economic interests. This problem is evident when she frames nationalist ideas in countries like North Korea as evidence for the salience of inward-looking economic models for nuclear decision-making. Yet, nationalism and inward-looking orientations are clearly not the same. Thus, Hymans (2010:30f.) poignantly asks: "what if they were also separated empirically? Would it turn out that tendencies toward "nuclearization" and "denuclearization" more strongly followed the pull of economic interests, or the tug of identity?"

Regime Type

Following the extant literature on the democratic peace, scholars have attempted to document the link between regime type and nuclear proliferation; focusing primarily on the distinction between democracies and autocracies (Way and Weeks 2014:4). Regretfully, little consensus has been reached about the supposed direction of the effect.

One view in the literature is that democracies are less likely to proliferate. Chafetz (1993) divides the international system into "core" and "periphery" states. The core constitutes liberal democracies with shared norms and values that have a long institutionalized experience with cooperation, which dampens the security dilemma and makes nuclear proliferation unlikely. States on the periphery, on the other hand, are more likely to proliferate because they have not yet established norms of peaceful cooperation among themselves due to little or no experience with liberal democracy. Some scholars have argued that domestic political opposition against nuclear weapons, particularly in the form of citizen's campaigns, have been influential in constraining weapons programs in Japan, Australia, and some European countries (Wittner 1997, 2003; Cirincione 2007:68–70). In the same vein, others have contended that autocracies are more likely to pursue a nuclear weapons program due to their ability to successfully stifle domestic opposition (Chubin 1994; Sheikh 1994).

Way and Weeks (2014) observe that, in addition to the mixed views on the effect of regime type on proliferation in the qualitative literature, quantitative studies have found at best trivial differences in the proliferation behavior of democracies and autocracies. They argue that earlier studies have missed a consequential regime type effect by fixating on the distinction between democracies and non-democracies, thereby obscuring important differences between various types of autocratic systems. Instead, they propose that "personalist dictatorships"—which they define as autocratic regimes where "a paramount leader enjoys enormous personal discretion over government decisions, to an extent unseen even in other dictatorships"—are prone to view nuclear weapons as effective guarantors of regime security and are less constrained in pursuing this option than leaders in democracies and non-personalist autocracies (Way and Weeks 2014:708). They test the hypothesis that personalistic regimes are more likely to *pursue* nuclear weapons than other regimes by running a number of statistical tests based on an original dataset that measures the extent to which a leader is free of constraints on his personal rule. Their findings indeed indicate that personalism is strongly associated with the pursuit of nuclear weapons.

Building on the Weberian concept of "patrimonialism," Hymans (2008, 2012a) suggests that regimes that fit the "neopatrimonial" or the more extreme "sultanist" category—regimes characterized by extreme personal rule, the use of intimidation and state resources to secure loyalty of clients, and a lack of checks and balances—will fail more often in moving from one technological threshold to the next and take longer to field an operational nuclear weapons arsenal, particularly when it comes to developing advanced levels of nuclear technology and weapons delivery systems due to bureaucratic incompetence. Montgomery (2013) draws on Hymans' work on neopatrimonialism and Kroenig's (2009b) and Fuhrmann's (2009a) work on nuclear assistance to test the hypotheses that neopatrimonial regimes will take longer to complete nuclear weapons projects and that such regimes are less able to make use of nuclear assistance from other states. He finds strong evidence that neopatrimonialism decreases the likelihood of a state moving from the pursuit to acquisition of nuclear weapons. His findings also indicate that neopatrimonial states that received civilian assistance did even worse than would be expected from the presence of either of those factors alone.

Cognitive and Psychological Factors

Hymans (2006) turns on its head the realist assumption that, given the opportunity, leaders would want a nuclear weapon for security purposes. Instead, he argues that few leaders desire nuclear weapons because to go nuclear is a leap in the dark, a revolutionary decision fraught with uncertainty regarding the state's technical ability to build a bomb as well as the national security implications of acquisition (cf. Lavoy 1993; Paul 2000). Such uncertainty challenges the idea that the decision to go nuclear can be made on the basis of a rational cost-benefit calculation, as is the case with security, domestic political, and prestige explanations of proliferation.

Hymans argues that leaders that have embarked on the path of joining the nuclear club hold an oppositional nationalist national identity conception (NIC)—that is, they view their nation as naturally at odds with another state and see themselves as equal (if not superior) to them. When faced with "the other," oppositional nationalist leaders tend to experience volatile emotions like fear and pride that predispose them to be highly motivated to acquire nuclear weapons. As a result, the mere arrival in power of oppositional nationalists is almost sufficient to instigate a proliferation decision, granted that some necessary conditions are met (the state has some experience in the nuclear field and is engaged in reasonably intense interaction with "the other," while the leader should have a reasonable degree of control over the state apparatus). In contrast, leaders holding different NICs tend to refrain from making a definitive commitment to acquire nuclear weapons, instead preferring to secure a nuclear security guarantee or to develop a significant nuclear technology base.

Hymans tests his theory against four country case studies (France, Australia, Argentina, and India) that confirm the importance of leaders' NICs. When oppositional nationalist leaders rose to power they rapidly decided to develop a weapons program, while leaders holding other identity conceptions refrained from making that decision. Nonetheless, Hymans' work has some understandable limits. While his conceptualization of NICs and their influence on the behavior of individual leaders is remarkably well argued, he treats those identities as given and does not explore how they are formed or whether and how they can change over time. Moreover, it remains to be seen to what extent Hymans' theory can be generalized beyond his four case studies.

2. Quantitative Studies of Nuclear Proliferation

As is apparent from the first part of this article, the study of nuclear proliferation has generated plenty of literature on factors that influence states' nuclear-weapons decisions. While existing theories highlight important parts of the proliferation puzzle, no theory can provide a sufficient explanation on its own for such an inherently complex process. On the contrary, history has shown that nuclear proliferation and restraint have occurred for various reasons, suggesting that multicausality—or rather complex causality—lies at the heart of the puzzle (Sagan 1996:85).[16]

While the majority of the proliferation literature has been of a theoretical/conceptual nature or has focused on individual detailed case studies or small-N between-case variation, a plethora of quantitative studies since 2004 have concentrated on systematically testing hypotheses regarding the causes of nuclear proliferation across all states over a long period of time.[17] These studies have produced findings that are an important addition to the proliferation literature, while also raising serious questions. First, they have far from settled the debate about the causes of (non)proliferation because their findings often contradict one another. Second, these studies contain significant design issues that sow doubt on the validity and usefulness of said findings.

In the following, I discuss five studies that quantitatively explore the causes of nuclear proliferation (namely, Singh and Way 2004; Jo and Gartzke 2007a; Fuhrmann 2009a; Kroenig 2009b; Bleek and Lorber 2014). The first section illustrates how a significant part of their results are contradictory. Subsequently, I discuss four shortcomings that further throw doubt on their findings. To be sure, all works discussed here are insightful and nuanced, and have contributed to a lively debate in the field of proliferation studies. This endeavor is not intended to demean the authors or to obscure the merits of quantitative research in the field of International Relations. It does, however, serve to illustrate how conventional large-N statistical research—and its conventions and best practices—may produce results that are compromised in their reliability and validity, and does not necessarily provide the type of knowledge that is useful to understand and confront the spread of nuclear weapons.

[16] Rublee (2009) and Knopf (2012), for instance, show that their main variables of interest (anti-nuclear public sentiment and security assurances, respectively) led to nuclear restraint when combined with or complemented by other factors.
[17] Montgomery and Sagan (2009) refer to this group of studies, kick-started by Singh and Way (2004), as the "second-wave" to distinguish it fom early efforts by Kegley (1980) and Meyer (1984).

Findings

Starting with supply-side variables, Singh and Way (2004) find evidence that GDP is positively related to the pursuit of nuclear weapons, whereas it is positive but insignificant for exploration and acquisition of weapons. Kroenig's (2009b) censored hazard model indicates it is positive but insignificant for acquisition of weapons, while Fuhrmann (2009a) finds no relationship between GDP and weapons activity at all.[18] All three authors do find strong evidence that having a minimum industrial threshold increases the odds of proliferation. Results for the influence of nuclear assistance, however, are confounding. While Kroenig as well as Fuhrmann report that sensitive and civil nuclear assistance are strongly and positively related to proliferation, Bleek and Lorber (2014) find that civil and sensitive assistance have a positive effect on exploration and pursuit, but a negative effect on acquisition. However, only the effect of sensitive assistance on exploration is statistically significant.

Turning to the external security environment, Singh and Way (2004) report that security threats are strongly and positively correlated to the exploration, pursuit, and acquisition of nuclear weapons, while Fuhrmann (2009a) only finds weak evidence that it increases odds of acquisition and Kroenig (2009b) finds threats to be insignificant for acquisition. Jo and Gartzke (2007a) interestingly find that conventional threats encourage proliferation, while nuclear threats discourage them. However, Bleek and Lorber (2014) report that nuclear threats discourage pursuit of nuclear weapons (though the result is insignificant), but encourage exploration and acquisition. Finally, four out of five studies find that having a nuclear ally has little or no significant effect on preventing proliferation. Bleek and

[18] While the variable is highly significant in Kroenig's (2009b) uncensored model, such models are inferior as will be discussed further below (see p. 29f.).

Lorber, however, question these result and report that nuclear security guarantees have a negative and significant effect on proliferation propensity.

The final group of widely assessed variables concerns domestic politics factors. According to Singh and Way (2004), Jo and Gartzke (2007a), and Kroenig (2009b), democracy tends to encourage proliferation though the authors find varying evidence for which stages of proliferation this effect holds. In Fuhrmann's (2009a) and Bleek and Lorber's (2014) studies, however, democracy does not reach significance for any stage of proliferation. The results concerning the role of economic openness seem to garner consensus: all studies find the variable to be insignificant. Finally, Kroenig as well as Fuhrmann indicate that economic liberalization increases the odds of acquisition, while Singh and Way find the variable to decrease odds of exploration and increase odds of pursuit. Finally, Bleek and Lorber report liberalization to have a positive but insignificant effect across all stages of proliferation.

Issue I: Measuring Independent Variables

The first problem that calls into question the findings of quantitative proliferation studies concerns the validity of the (proxy) measures employed. For a measure to be valid it has to closely approximate the meaning of the concept that the researcher is interested in measuring (King, Keohane, and Verba 1994:25). It is then problematic when researchers measure what is easily measured rather than develop original datasets that adequately capture the concepts they are interested in (Montgomery and Sagan 2009; Mearsheimer and Walt 2013).

For an example of this issue we can turn to attempts to construct an index of states' latent capability to build nuclear weapons. Meyer (1984), Stoll (1996), and Jo and Gartzke (2007a) use automobile and television manufacturing experience to measure whether a state is able to build the non-nuclear explosive components needed for a nuclear weapon. Meyer (1984:191) argues that all that is required is the "relatively unsophisticated design/construction of the fusing detonator system"—which he assumes that states with motor vehicle or radio/television manufacturing experience should be able to do. Yet, the manufacture of explosive components for nuclear weapons is significantly more complicated than assumed by these authors.[19] This requirement constituted such a barrier that Iraq suffered significant setbacks for years when trying to develop the non-nuclear components for its weapons program before the 1991 Gulf War (Jones, McDonough, Dalton, and Koblentz 1998:322). Hence, those interested in the technical ability of states to build the explosive components for nuclear weapons could construct datasets on arms manufacturing experience rather than rely on crude proxy measures such as automobile and television manufacturing that do not adequately measure the concepts that they are interested in.

Issue II: Coding Dependent Variables

The second challenge concerns the treatment of states' proliferation status (the dependent variable). Singh and Way (2004) conceive of a state's proliferation trajectory as a multi-step-process with four stages of proliferation: 1) no interest; 2) exploration of a nuclear weapons option; 3) pursuit of nuclear weapons; and 4) acquisition of nuclear weapons. Jo and Gartzke (2007a) follow this multi-step approach but code states as either pursuing or acquiring nuclear weapons. The veil of secrecy that usually shrouds nuclear programs makes it difficult to determine when states have explored, pursued, and acquired nuclear weapons. This is reflected in the different coding systems used for the dependent variable, where there even is a lack of consensus on proliferation dates for

[19] Jones et al. (1998:322) describe that the manufacturing explosives for nuclear weapons requires "the design and fabrication of: specially designed high-explosive components to compress the fissile material core of the device; high-speed electronic firing circuits, or 'triggering packages' to set off the high explosives uniformly at precisely the correct instant; and in most designs, an 'initiator'—an intense source of neutrons to initiate the nuclear chain reaction in the core."

many well-known cases.[20] Accordingly, new (or neglected) confirming or disconfirming evidence has a significant impact on the robustness of findings in many studies. Adding omitted cases to Jo and Gartzke's dataset significantly affects their findings relating to the effect of nuclear threats, membership in the NPT, and the spread of nuclear technology (Montgomery and Sagan 2011).[21]

Nevertheless, these differences in coding of nuclear status cannot be solely attributed to the secretive nature of the endeavor. To some extent, such differences are the result of differing coding rules that the authors employ and some disagreement will always remain. Jo and Gartzke, for instance, look at decisions by officials, while Singh and Way look at both capabilities of states and political decisions. More fundamentally, however, the interpretation of proliferation events may be a product of the nature of nuclear technology. Scholars and analysts are often faced with uncertainty as regards the intention of a state's nuclear program: is the state pursuing nuclear weapons or nuclear energy (nuclear ambiguity), or does the state have nuclear weapons that it is not acknowledging (nuclear opacity) (Cohen and Frankel 1991)? This uncertainty of intentions is often solved in policymaking circles by erring on the side of caution and assuming the worst case scenario (cf. Booth and Wheeler 2008).

The tendency towards worst-case thinking mistakenly presupposes that all states have a dormant desire to build nuclear weapons. Yet, a majority of states do not seek *any* nuclear power and among the states that have, nuclear weapons have not been the only or even the common end station. Hence, there is a need for redefining our understanding of the relationship between nuclear weapons and nuclear energy. Abraham (1998, 2006, 2010) argues that nuclear technology is essentially ambivalent. The technology contains within itself simultaneously civilian and military applications,

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[20] For instance, Singh and Way code the United Kingdom as pursuing in 1947, whereas Jo and Gartzke code it as pursuing as early as 1941. Israel is coded by Jo and Gartzke as pursuing in 1955 and acquiring in 1966, while Singh and Way code it as pursuing in 1958 and acquiring in 1972.

[21] The following cases were added: West-Germany, Italy, Libya, Egypt, and Australia.

which makes it impossible for either path to be predetermined.[22] Actors do not have well developed intentions or preferences in this regard; they can be pushed in either direction depending on internal and external developments after the initiation of a nuclear program.[23] This is a crucial notion, for it means that we can never know for certain what the "true" intentions of a state are (Abraham 2010:54). Moreover, Abraham warns, international non-proliferation pressures on ambivalent governments—caused by uncertainty and resulting in worst-case assumptions—may have the ironic consequence of pushing them to resolve their ambivalence in favor of militarization.

As a result of all these constraints in determining a state's "degree of nuclearness," scholars conducting medium or large-N studies—whether quantitative or otherwise—would be best advised to measure nuclear status in such a manner that is a better (though not perfect) reflection of the realities of the proliferation process. Given the data constraints inherent to the phenomenon under study, Müller and Schmidt (2010:133) propose a simple approach by pooling together all nuclear activity in one category "nuclear weapons activities," based on the understanding that moving from "no interest" to "doing something" is the most substantial step and that the knowledge about this step is more accurate than the movement between other stages. In essence, researchers ought to specify what they want to understand about the proliferation process and, consequently, reflect on how much confidence in results they are willing to trade for information about more sub-steps of the process.

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[22] Ambivalence is different from the literature's characterization of nuclear technology as "dual-use," because dual-use emphasizes the "operator" of the technology rather than the "structural feature of technology itself" (Abraham 2010:55).
[23] Even if they have an intent towards the one or the other, they can be pushed in another direction through various political and social pressures (cf. Fuhrmann 2009a).

Issue III: Research Design

The third issue revolves around the design of quantitative studies. It is a given that steep data requirements of most quantitative techniques necessitate researchers to maximize the number of observations under study. Hence, quantitative studies treat nuclear proliferation as a large-N phenomenon, despite the fact that there are only two (or at most three) dozen states that have conducted nuclear-weapons related research or embarked on active weapons programs and even fewer states that have succeeded in acquiring functional nuclear weapons. One reflection of this practice is the choice of the country-year as the unit of analysis over a long period of time, which results in datasets that can contain many thousands of observations. The use of the country-year in combination with a large number of variables incentivizes the use of crude proxy measures as limited time and resources necessitate a tradeoff between the quantity and the quality of the data that is collected. The example of measuring states' latent capability to build nuclear weapons discussed earlier (see p. 25f.) illustrates how the data requirements of large-N studies can result in the use of sub-par measures.

Collecting large amounts of reliable data is further hampered by imprecise, dubious, or missing data. Consequently, researchers are confronted with the choice between settling for inaccurate data or dropping (a potentially significant number of) observations with missing or dubious data (Huth and Allee 2004:216f.). Dropping observations is problematic since data is often hard to obtain for cases with systematic similarities, such as developing countries or countries with closed political systems (Huth and Allee 2004:n. 4). Yet, retaining them in the analysis may not be an ideal scenario either as we can observe in our sample of proliferation studies. Singh and Way (2004:867ff.), for instance, report that GDP and trade data (which they use to construct their GDPpc, economic openness and economic liberalization variables) are not available for all countries during all periods in their primary data source (the Penn World Tables project [PWT]).[24] For the data not covered by PWT, they turn to Gleditsch's (2002) expansion of PWT's GDP data and the International Monetary Fund's (IMF) trade data. A significant part of Gledistch's data, however, is obtained through various estimation and interpolation procedures. After all of this, roughly 15% of country-years in Singh and Way's dataset still lack data on the GDPpc, economic openness, and economic liberalization variables.[25]

Aside from the problem of data availability and quality, large-N approaches have also caused significant research design flaws in existing studies of nuclear proliferation that throw serious doubts on their findings. Singh and Way (2004), for instance, employ hazard models and multinomial logistic regressions to separately analyze each proliferation stage, but neglect to restrict the pool of states to those at the preceding stage of development. This means that states that have never had any interest in nuclear weapons (stage 1: *no interest*) are nevertheless included in the analysis of pursuit of nuclear weapons (stage 3: *pursuit of weapons*), without first having explored (stage 2: *exploration of weapons*). Similarly, states that have never explored (stage 2) and pursued (stage 3) are nevertheless included in the analysis of acquisition (stage 4). Montgomery and Sagan (2009:311) rerun the analysis by dropping all cases that were not already at the previous level of development, which decreases the number of observations from 5,578 to 250 for the analysis of pursuit (stage 3) and from 5,784 to 210 for the analysis of acquisition (stage 4). Their re-estimation of Singh and Way's hazard models with the trimmed datasets causes very few variables to remain statistically significant. In the acquisition stage the data are so sparse that the algorithm does not even converge properly.

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[24] PWT 6.1 (Heston, Summers, and Aten 2002) covers the period 1950-2000. Approximately 30% of observations in the population are missing in the PWT data. Additionally, PWT lacks data for the first five years (1945-1949) of Singh and Way's study.

[25] These issues also occur in Fuhrmann (2009a), Kroenig (2009b), and Bleek and Lorber (2014), as they employ Singh and Way's dataset and variables.

Jo and Gartzke (2007a) do censor their probit models of pursuit and acquisition for states at the previous stage of development. Unlike Singh and Way, however, they do not remove states from the risk pool for starting a weapons program once they begin but retain them for the entire duration of the model. As a result, long-running programs like that of the United States (which is coded as having a program since 1942 but already acquired weapons in 1945) have a disproportionate impact on the findings. Again, most variables either become statistically insignificant or their effects change after these issues are resolved by Montgomery and Sagan (2009:312f.).

Finally, both Bleek and Lorber (2014) and Kroenig (2009b) include models that are restricted to states at the previous level of development. In Kroenig's (2009b:170ff.) case, few variables remain statistically significant after censoring compared to the uncensored models, though his main variable of interest (sensitive assistance) remains significant. In their robustness checks, Bleek and Lorber (2014:441) find that censoring causes almost all independent variables to become statistically insignificant, including their main variable of interest (security guarantees). Some models do not even complete because of the small number of states that have actually pursued or proliferated.

Until now, I have considered how large-N research designs required for quantitative analysis have led to problematic research practices. Such practices are less likely to occur in studies with a smaller N. Moreover, a small or medium-N design better reflects the phenomenon under study. To be specific, cases where the outcome of interest (proliferation) is impossible—for example, states that cannot afford a nuclear weapons project or have never even showed interest in a civilian nuclear program—are essentially irrelevant observations when studying the causes of proliferation. Assuming that all cases are relevant leads the researcher to waste time and resources on analyzing a large number of cases that add little to our knowledge for the outcome was impossible. At the same time, artificially inflating the number of observations can make a false or weak theory look much stronger than it really is (Mahoney and Goertz 2004:655f.).

Advocates of large-N statistical approaches will criticize selecting negative cases because it ignores or underemphasizes states that never pursued nuclear weapons and therefore overestimates effects that do not exist and/or underestimates effects that do exist (Geddes 1990:132f.; King et al. 1994). However, selecting irrelevant cases can result in including too many (irrelevant) negative cases and therefore produce inaccurate causal inferences similar to a sample with too many positive cases (see Clark and Nordstrom 2003). For our purposes, we can say that states that have never worked on nuclear weapons are in a different category than those that explored/pursued weapons but reversed course. For past exploring/pursuing states, nuclearization was an option, albeit one that was (eventually) rejected or forestalled. These are the Y=0 cases of interest. However, most states do not consider or desire *any* nuclear technology, let alone nuclear weapons (Abraham 2010). In other words, there is a qualitative difference between states that have never entertained the nuclear option and states that have explored the option or actively pursued weapons but did not proceed to the acquisition of nuclear weapons.[26] The proliferation puzzle is therefore best characterized as a small or medium-N phenomenon, rather than a large-N one.

Issue IV: Quantitative Methods and Causality

Research on the causes of proliferation involves investigating a large number of factors that influence decision-making on an individual and collective level. Proliferation scholars recognize the complex nature of the proliferation process, seeing as they employ ever more sophisticated statistical techniques to investigate different proliferation hypotheses. However, their research aims and methods produce the type of knowledge that is less suited to understanding the intricate process of

[26] Even if one were to argue that states that have not explored and/or pursued but have had the economic and technological wherewithal to develop nuclear weapons (in other words, opportunity) should be considered relevant cases, the sample would yield maybe three or four dozen states for the exploration stage. The negative cases for the pursuit and acquisition stage would be limited to the states that had already made it to the preceding stage of development.

proliferation, let alone to create policy to combat it. Quantitative methods assess the *net effect*—that is, the non-overlapping contribution—of each independent variable on the explained variation in the dependent variable. The ability to evaluate the relative importance of competing explanations makes such methods particularly suited for theory adjudication (Ragin 2008:177–179).

While it can be useful to determine the relative importance of independent variables, social science theories frequently do not oppose one another and do not necessarily compete. Research on the spread of nuclear weapons has shown that causal conditions do not act independently but combine in complex ways to motivate or dissuade states from seeking nuclear weapons. It is likely that causal conditions display their impact on the outcome in a certain way only when combined with other factors, also known as *conjunctural causation*.[27] It is also likely that there are multiple causal paths to the same outcome (for instance, a decision to initiate a weapons program), meaning that there is *equifinality*.[28] Combining these two notions, a given outcome may be produced by a given condition when it is present and also when it is absent.[29] This understanding of causality runs counter to the basic assumptions of conventional statistical approaches such as (linear) additivity, which means that the net effect of each independent variable on the outcome is assumed to be the same irrespective of the values of other factors.

To progress towards a comprehensive understanding of the proliferation process, we must not only examine the net effects of independent variables but also systematically investigate the different ways that combinations of causal conditions combine to produce proliferation outcomes across cases. Rather than being an exclusively academic exercise, such research also has societal relevance.

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[27] Conjunctural causation is, for instance, expressed in the following model: **A*B → Y** (with * indicating the Boolean operator AND).

[28] Equifinality is, for instance, expressed in the following model: **A + B + C → Y** (with + indicating the Boolean operator OR).

[29] Consider the following model: **A*B + a*C → Y** (with uppercase letters indicating presence of a condition and lowercase letters indicating its absence).

Simply put, for policy-making it is more relevant to understand which conditions are significant in which contexts rather than knowing which theoretical perspective best succeeds in explaining variation in the outcome (Ragin 2008:182).

3. Directions for Future Research

The body of literature reviewed in this article highlights that the proliferation puzzle is inherently complex. This characterization should not cause concern but excitement, as it is a testimony to the health and productivity of proliferation scholarship. A spate of new research since the turn of the millennium has combined insights from various disciplines, such as political science, sociology, psychology, international law, political economy, and history, to formulate new or enhanced accounts of the causes of nuclear proliferation and restraint. Notably, this research has definitively shown the importance of domestic politics, norms, identity, and the psychology of individuals in a field traditionally inclined towards state-centered, military security-oriented explanations. Moreover, proliferation research crosses methodological boundaries, making innovative use of quantitative approaches, archival research, surveying, formal modeling, process tracing, and discourse analysis, to name but a few. Nonetheless, it is inevitable that many questions remain. I group some of these in three categories that can serve as the basis of further research.

The Non-Proliferation Regime

One of the most pressing questions surrounding the non-proliferation regime is how the inherent unfairness of the NPT's 'grand bargain' and the selective implementation of its provisions will bear on the survival of the nonproliferation regime and the proliferation propensity of states. One view is that NNWSs will no longer accept the obstinate refusal of NWSs to make meaningful progress on nuclear disarmament, the restriction of NNWS access to civilian nuclear technology, and the rehabilitation or even rewarding of proliferators that choose to remain outside of the NPT (India, Pakistan, and Israel), which will lead to states leaving the NPT (with or without the intent to develop nuclear weapons) and an eventual collapse of the nonproliferation regime.[30] On the other hand, some NNWSs oppose nuclear disarmament, though they may not voice this publicly, because they enjoy the benefits of a nuclear guarantor or prefer the perceived stability of a nuclear world to the perceived instability of a conventional one (Knopf 2012). Whether the lack of progress on disarmament (but also the restriction of technological assistance or the inherent discriminatory nature of the NPT) will lead to less or more proliferation is unclear. Unraveling this question requires more historical research focused at finding out why states joined the NPT, how their attitudes have changed over time, and why they continue to adhere to the Treaty.

While the NPT is the cornerstone of the global non-proliferation regime, recent years have seen the birth of many complementary formal and informal agreements, such as the Proliferation Security Initiative, Security Council Resolution 1540 and the 1540 Committee, the Comprehensive Nuclear-Test-Ban-Treaty, and the Nuclear Suppliers Group. Yet, most of these instruments have not received nearly as much scholarly attention as the NPT and much can be learned from research on their genesis, workings, and effectiveness in relation to the (non)proliferation of nuclear weapons.[31]

Nuclear Technology

As soon as the immense power of nuclear weapons was demonstrated at the end of World War II, it became clear that the dual-use nature of nuclear technology would pose significant problems. A 1946 report commissioned by the U.S. Secretary of State noted that, "the development of atomic energy for peaceful purposes and the development of atomic energy for bombs are in much of their

[30] Others, however, argue that the relevance of these collapse triggers in shaping states' views of the NPT is exaggerated (see, for instance, Horovitz 2015).
[31] On the NPT see, for instance, Shaker (1980), Swango (2009), and Joyner (2009:chap. 1, 2011).

course interchangeable and interdependent" (Lilienthal, Barnard, Oppenheimer, Thomas, and Winne 1946:4). As much of the technology and knowhow necessary for civilian programs is useful for military applications, such programs, particularly highly developed ones, may permit well-connected individuals with an interest in nuclear weapons to argue that proceeding with a military program is easy. Therefore, it is first necessary to understand in which ways civilian nuclear programs create demand for nuclear weapons and, conversely, how domestic actors (such as, scientists, administrators, and politicians) and the international community can prevent such programs from turning into military ones. Second, it is useful to understand how the makeup of a civilian program—for instance, its size, scope, stage of development, choice of particular technologies, and contribution to a state's overall energy needs—influences the timeline towards the development of a nuclear-weapons capability. Third, it is crucial to explain why a large majority of states has shown no interest in pursuing nuclear power. As Abraham (1998, 2006, 2010) explains, nuclear technology may be characterized as inherently ambivalent and nuclear programs are often initiated without a definitive goal in mind—that is, a strictly civilian program, a strictly military program, or both. Hence to properly understand why states end up with nuclear weapons, it is necessary to know why so many states reject nuclear power altogether.

In recent years, scholars have looked at how foreign nuclear assistance, whether for civilian or for military purposes, influences the spread of nuclear weapons. Empirical work has purported to show that civilian nuclear assistance "tempts" states to look for nuclear weapons (Fuhrmann 2009a). Yet, it remains unclear whether states become more prone to proliferate as a consequence of civilian assistance or that they actively seek civilian assistance because they desire or consider nuclear weapons. Research is also needed to better understand the various adverse effects that nuclear assistance can have on weapons programs. Hymans (2011), for instance, usefully shows that 'Atoms for Peace' policies ironically led to a brain drain from Yugoslavia's weapons program, while

Montgomery (2013) shows that sensitive assistance often creates setbacks because states with neopatrimonial regimes have trouble absorbing technologies they have not developed indigenously.

Empirical Testing

Despite the theoretical and methodological problems in quantitative studies of nuclear proliferation discussed earlier, it is important to continue the empirical investigation of (non)proliferation hypotheses in a systematic way across all relevant cases of proliferation and restraint. Scholars can further improve the research on the causes of proliferation by developing measures that correspond more accurately with the underlying concepts under study. In doing so, political scientists should collaborate with colleagues from other disciplines, such as nuclear physicists, to develop more accurate measures relating to, for instance, states' nuclear fuel cycles.

More fundamentally, scholars should adapt their research design and choice of methods to the requirements of the puzzle. Whereas quantitative studies of proliferation employ a large sample size, nuclear proliferation is essentially a small to moderate-N phenomenon. Treating it as large-N requires researchers to artificially maximize observations, which allows for many irrelevant observations to influence the outcome and increases the likelihood of using questionable data. Moreover, the use of statistical techniques is useful for understanding what the relative explanatory power of different theories (or rather variables) is. Yet, if we understand the proliferation process as being complex, that is, a process where different combinations of conditions can lead to the same outcome in different groups of cases, the use of statistical techniques might not be the ideal way to come to understand it.

Dealing with causal complexity represents something of a challenge for regression methods. Interaction effects can be used to account for conjunctural causation (that is, the intersection of two or more conditions represented by the logical operator AND) by determining the combined effect of variables. Nevertheless, very few have tried so while investigating the causes of proliferation.[32] The lack of application in the field of proliferation studies may be explained by the steep data requirements for higher-order interaction effects—a significant constraint in the study of nuclear proliferation[33]—and the difficulty of interpreting interactions consisting of more than two variables. Accounting for equifinality, the notion that "many roads lead to Rome" (represented by the logical operator OR) is even more problematic for quantitative methods due to the assumption of linear additivity (Braumoeller 2003:211; Ragin 2008:113).[34]

These issues do not mean that the field can only rely on theory or single case and small-N comparative studies, but rather that it needs to innovate in other ways than resorting to conventional regression methods. On the quantitative side, Müller and Schmidt (2010) deal with the data constraints of the field by forgoing complex quantitative approaches, instead conducting simple chi-square tests of several proliferation hypotheses. On the qualitative side, configurational methods such as Qualitative Comparative Analysis (see, for instance, Ragin 2008; Rihoux and Ragin 2009; Schneider and Wagemann 2012)) or its younger cousin Coincidence Analysis (see Baumgartner 2009) can deal with the equifinal and conjunctural nature of the proliferation process, while taking into account a small to intermediate number of cases.

[32] Fuhrmann (2009a) and Montgomery (2013) are prominent examples of studies where an interaction effect is tested.
[33] Montgomery (2013), for instance, encounters difficulties in statistically determining interaction effects due to a limited number of observations.
[34] Braumoeller (2003) proposes econometric procedures to test theories that posit multiple causal paths. These techniques, however, have hefty data requirements and their results are difficult to interpret (Vis 2012:173f.).

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