The Past and Future of Nuclear Proliferation

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Project Abstract
A rich literature has identified a number of important drivers of nuclear proliferation. Most of this work, however, treats the determinants of proliferation as constant over the entire nuclear age—the factors leading to proliferation are assumed to be the same in 2010 as they were in 1945. But there are reasons to suspect that the drivers of proliferation have changed over this time: nuclear technology is easier to come by, the global strategic environment has shifted, and the nuclear nonproliferation regime has come into being. We have also seen a change in how states approach nuclear development, as covert nuclear weapons programs have given way to the build-up of latent nuclear capabilities. This project identifies the ways in which the drivers of nuclear proliferation and the pathways for weapons development have changed and examines what these changes mean for assessing the proliferation risk of individual countries. The changing landscape of proliferation calls for a corresponding adjustment in nonproliferation posture—how the international community positions itself to limit the spread of nuclear weapons in the future.

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Chapter 2: A Theory of Change in Nuclear Proliferation

The US intelligence community is periodically asked to identify the countries at greatest risk of seeking nuclear weapons in the near future. According to a now-declassified National Intelligence Estimate, the list of worrisome states in 1964 included India, Israel, Sweden, West Germany, Italy, Japan, and Canada (Central Intelligence Agency 1964).[1] Although no such estimate from recent years is publicly available, unclassified assessments look quite different from 1964's usual suspects. Today's lists of the states most at risk of seeking nuclear weapons in the near future generally include Iran, of course, but often also mention Saudi Arabia, Turkey, South Korea, Egypt, and Japan.[2]

Why does today's list of potential proliferant states bear so little resemblance to those published in the 1960's? The circumstances of some individual countries have clearly changed. Italy, Sweden, Canada, and a reunified Germany face far different security threats today than at the height of the Cold War. And some of the states on today's list probably would not have been seen as having sufficient wealth or resources to plausibly acquire weapons in the 1960s. But these lists may also differ for a broader reason: our understanding of what drives states to seek nuclear weapons has

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[1] Of these, US intelligence analysts believed only India, and "perhaps Israel and Sweden," would actually develop weapons over the next ten years (Central Intelligence Agency 1964).

[2] There are many such lists produced by think tanks and foreign policy analysts, with fairly wide agreement about the candidate countries. For representative examples, see Allison (2010) and Spector (2016).

fundamentally changed. The spread of both civilian and sensitive nuclear technology has made indigenous capabilities and technical resources less essential to a successful nuclear effort. At the same time, the global strategic environment has shifted since the beginning of the Cold War, with a corresponding change in the credibility of nuclear alliances and security commitments. The first nuclear weapons also were developed outside the constraining effect of the set of international treaties, agreements, and norms that make up today's nuclear nonproliferation regime.

Understanding the changing drivers of nuclear proliferation is of clear importance to researchers and analysts. But a shift in *how* states actually go about developing nuclear technology may have even deeper implications for designing effective nonproliferation policy. The preferred pathway to proliferation—long thought to be a small, covert nuclear weapons program—may be changing, with the result that future proliferating states seem more likely to repurpose civilian nuclear facilities for weapons purposes. If true, this shift has a number of important implications for policymakers seeking to limit the spread of nuclear weapons.

The extensive academic literature on nuclear proliferation and nuclear restraint, while it has generated many important insights, does not provide much help in understanding the changing face of nuclear proliferation. Research employing quantitative methods has seen particular growth, but this work makes very strong assumptions about the extent to which the drivers of proliferation have remained static over time. By pooling all available cases for a single analysis, existing research, in effect, treats the fundamental dynamics of nuclear proliferation as unchanged since the dawn of the nuclear age. With a few notable exceptions, the academic proliferation literature has largely ignored altogether the question of how states pursue weapons, giving us little purchase in understanding states' choice of a nuclear pathway, let alone whether these pathways have remained static over time.

This chapter lays out a theory of change for the drivers of nuclear proliferation and the means by which states seek weapons. I argue that supply-side factors—the underlying capabilities of states and their ability to access nuclear technologies—have become less important in the decision to seek weapons over time, and I generate competing hypotheses about the changing influence of demand-side factors and international institutions. Once a decision is made to pursue nuclear weapons development, states must choose which proliferation pathway to follow. I focus here on the choice between using generally smaller, secret facilities or overt civilian nuclear capabilities to produce material for weapon, arguing that the use of overt facilities has become more attractive for states over time.

This approach treats nuclear proliferation as a dynamic, rather than static, phenomenon. If my theory is correct, it suggests that we should treat with caution the literature's recent emphasis on supply-side drivers of nuclear proliferation. Latent industrial capacity and other supply-side factors were undoubtedly important for the first nuclear states, but the lessons from those nuclear programs may be less relevant for the states at greatest risk of seeking nuclear weapons today. A similar argument applies to our current policy emphasis on detecting secret nuclear programs in states of concern. While finding hidden weapons work is undoubtedly important, it may be necessary to expand the range of policy tools to deal with a world where overt hedging strategies or nuclear breakout attempts are becoming more likely.

This chapter proceed in three parts. In part one, I focus on the drivers of proliferation—why states seek weapon. I highlight the potential dangers of reasoning from past cases and propose a theory of change in nuclear proliferation, generating hypotheses about the importance of various drivers of proliferation over time. Part two addresses changes in proliferation pathways—how states seek weapons. I describe the possible drivers of the selection of one pathway over another and theorize about changes in the dynamics of nuclear proliferation that might lead states to prefer an overt nuclear infrastructure for nuclear development. The chapter concludes with a brief discussion of the implications of these theories for the proliferation literature and nonproliferation policy.

The Drivers of Nuclear Proliferation

The literature on nuclear proliferation has identified a number of factors that may affect state decisions to seek nuclear weapons. These drivers of proliferation and nuclear restraint can be divided into three broad categories: nuclear capabilities (supply-side factors), nuclear motives (demand-side factors), and international institutions.

Nuclear capabilities

Industrial and economic capacity have long been seen as the most important pre-requisite for nuclear weapons pursuit. A full-scale nuclear weapons programs requires financial resources, access to particular raw materials, specialized industrial facilities, and advanced engineering and scientific expertise. States lacking these resources, scholars have argued, represent little risk of proliferation, no matter how much they desire a weapon.

Empirical findings in the literature have largely found support for the importance of supply-side factors in driving proliferation. A body of research has identified significant links between economic capacity and proliferation behavior (Fuhrmann and Berejikian 2012; Horowitz and Narang 2014; Singh and Way 2004; Way and Weeks 2014), and an even stronger association between industrial or latent nuclear capability and weapons programs (Bleek and Lorber 2014; Fuhrmann 2009; Fuhrmann and Tkach 2015; Jo and Gartzke 2007; Miller 2014b; Singh and Way 2004; Way and Weeks 2014). Gartzke and Kroenig (2009) conclude that supply-side factors—to include state capability—"are among the most important determinants of nuclear proliferation."

Advocates of supply-side theories of nuclear proliferation also have focused on the provision of nuclear assistance to would-be proliferants. By lowering the barriers to a successful nuclear weapons effort, nuclear assistance may make states more likely to take the initial step and launch a nuclear weapons program. Studies that have examined the role of nuclear assistance in encouraging proliferation have found that sensitive assistance, bilateral civilian assistance, and multilateral civilian assistance are strongly associated with the decisions of states to seek nuclear weapons (Brown and Kaplow 2014; Fuhrmann 2009; Kroenig 2009)[3].

[3] For contrary views, see Miller (2017) and Montgomery (2013).

Nuclear motives

The most basic driver of nuclear weapons pursuit is a state's concern about its own security (Sagan 1996). States justify the expense and risk associated with seeking weapons largely in terms of the security benefits they believe will follow from nuclear acquisition. Countries that have been more frequent participants in international conflict—or that expect to be involved in conflict in the future—will find the cost of nuclear weapons development easier to justify. It is no surprise, then, that a number of studies have shown an association between nuclear weapons pursuit and a state's conflict behavior (Brown and Kaplow 2014; Fuhrmann 2009; Fuhrmann and Horowitz 2015; Fuhrmann and Lupu 2016; Miller 2014b; Singh and Way 2004), the proliferation decisions of neighbors or rivals (Fuhrmann 2009; Fuhrmann and Berejikian 2012; Fuhrmann and Horowitz 2015; Fuhrmann and Lupu 2016; Singh and Way 2004), and the presence of an alliance or security guarantee from a nuclear-armed patron (Bleek and Lorber 2014; Fuhrmann and Horowitz 2015; Gerzhoy 2015; Reiter 2014).[4]

A number of other factors may affect a state's desire for nuclear weapons. Several scholars have found a relationship between the type of regime or the psychology or experiences of its leader and the decision to pursue nuclear weapons (Fuhrmann and Horowitz 2015; Hymans 2006; Way and Weeks 2014). The openness of a particular

[4] None of these findings are universal, however. For alternative results on nuclear rivalry, see Jo and Gartzke (2007), and on alliances, see Fuhrmann (2009) and Brown and Kaplow (2014).

regime to the international economy, too, may moderate the desire to proliferate, as may norms of nonproliferation behavior (Rublee 2009; Solingen 2007).

Institutions

Since the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) came into force in 1970, only four states have acquired nuclear weapons, and no state has acquired nuclear weapons while a member of the NPT.[5] For some, this is strong evidence of the effectiveness of the NPT in constraining state behavior. The NPT has been hailed as one of the most successful security treaties in history (Cirincione 2008), chiefly because it is seen as a key factor in keeping the number of nuclear weapons states far below the dire predictions of the 1960's.[6]

A number of studies have examined the possible constraining role of the NPT in at least a cursory way. Quantitative analyses have found that whether a state is a member of the NPT in a given year is often significantly associated with a decreased likelihood of proliferation (Bleek and Lorber 2014; Brown and Kaplow 2014; Fuhrmann 2009; Jo and Gartzke 2007). As these authors acknowledge, however, the significant negative correlation between NPT membership and nuclear weapons programs does not tell us much about the independent role of the NPT, because there is likely to be a powerful selection effect with regard to treaty membership. If states are more likely to join the

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[5] One state that acquired nuclear weapons, South Africa, later gave them up and joined the NPT. North Korea only reached nuclear weapons status after withdrawing from the NPT.

[6] Most famously, President Kennedy warned in 1960 that dozens of states might join the nuclear club by the 1970s (Firmage 1969).

NPT when they have no intention of proliferating, as we might expect, then this correlation may have little to do with the constraining power of the treaty.[7]

Temporal pooling in studies of proliferation

This body of proliferation research uses past cases of weapons pursuit or restraint to offer—at least implicitly but sometimes quite openly—lessons for academics and policymakers examining today's nuclear proliferation challenges. Scholarship on proliferation promises more than a history lesson; it is useful and important because it advances our understanding of an international security issue of continuing relevance.

When we reason from past cases, we assume that the underlying dynamics of proliferation in the past are similar to those at play today. Studies whose research design employs detailed case studies or historical analysis commonly make this assumption explicit. In justifying the decision to focus on a particular set of cases or historical examples, scholars defend the external validity of their analysis and explain why their findings are relevant beyond the set of cases that have been chosen.

Studies that adopt a quantitative approach, however, frequently skip this step; it often seems unnecessary to justify the scope of an analysis that employs the full universe of cases. But empirical models constructed from all previous cases make very strong assumptions about the extent to which the drivers of proliferation have remained unchanged over time. Quantitative approaches to nuclear proliferation typically begin with a dataset that pools nearly all country-years since 1938 or 1945—including states

[7] For analysis that seeks to avoid this selection problem, see Fuhrmann and Lupu (2016).

with and without nuclear weapons programs—into a single dataset. Regression models that analyze pooled datasets assume a common data-generating process over the full dataset; these static parameter models assume that the effect of a given explanatory variable on the likelihood of an outcome is the same for observations in 1945 as for observations in 2010.

Researchers can allow the effects of variables of interest to change over time in a traditional regression framework by interacting temporal dummy variables with key explanatory variables, but results from this approach can be cumbersome to interpret and it is rarely employed in practice. More commonly, scholars will disaggregate their data by time period,[8] but this approach calls for the analyst to identify sometimes-arbitrary breakpoints. Methods expressly designed to identify variation in effects over time, such as change point analysis, while expressly designed to identify variation in effects over time, are better suited for data with significant structural breaks than those that exhibit gradual temporal changes.[9] General time-varying effects models can require more data for valid inference and have not been widely adopted in the international relations literature.[10] None of these methodological approaches have been applied to the case of nuclear weapons proliferation.

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[8] See, for example, Farber and Gowa (1997) and Gowa (1999)

[9] On change point analysis in political science, generally, see Spirling (2007) and Western and Kleykamp (2004). For a recent application in international relations, see Nieman (2016). Park (2010) employs a Poisson state space model that allows parameters to vary more frequently than in most change point methods, but this approach can be difficult to implement in a hypothesis-testing framework.

[10] For a general description of this class of models, see Hastie and Tibshirani (1993). A recent application in international relations is Anderson, Mitchell, and Schilling (2016).

One risk, then, in adopting standard regression models with pooled data, is that this approach will obscure important temporal variation for factors of interest. Regression coefficients that appear statistically and substantively significant based on the full pooled dataset may fail to reach significance within time-limited subsamples of the full dataset. This may be a particular problem in studies of nuclear proliferation, where cases of nuclear pursuit are quite rare and unevenly distributed over time. Cases from early in the nuclear age, such as the United States and Soviet Union, can have a disproportionate influence on the results of the analysis. It may be that the dynamics of proliferation were simply different for the earliest nuclear states; perhaps proliferation is not what it used to be.

A theory of change in the drivers of nuclear proliferation

How might the drivers of nuclear proliferation have changed over time? I examine this question for each of the three broad categories of proliferation theory described above: nuclear capabilities, nuclear motives, and international institutions.

Nuclear capabilities

We might expect that supply-side considerations had a greater impact on state decisions to pursue nuclear weapons early in the nuclear age than they did in more recent years, for several reasons. First, knowledge of the nuclear fuel cycle, weapons design, and weaponization has become much more widespread over time.[11] While

[11] Tacit knowledge, however—the knowledge of nuclear processes that comes from trial and error—may have spread more slowly. See Montgomery (2005).

scientists in the US and Soviet nuclear programs had to work out most of the details of nuclear reactions on their own (or with help from espionage), the physics of nuclear weapons are now broadly understood and openly published. Technical barriers to uranium enrichment and nuclear reactor design that required tremendous resources to overcome in the first nuclear programs are now routinely covered in nuclear engineering courses worldwide. Easier access to nuclear knowledge reduces the cost to states of pursuing a nuclear weapon; prospective proliferant states need not budget for a Manhattan Project when a good portion of the initial legwork has been done for them.

Second, would-be nuclear states now have several options for obtaining knowledge and technology necessary for nuclear weapons development. While the early weapons states once held nuclear secrets closely, the spread of global nuclear power has opened up a number of sources of nuclear assistance. States may, of course, still receive weapons-related help from their nuclear allies (Kroenig 2009b). But they may also benefit from civilian nuclear cooperation agreements or multilateral nuclear aid from the International Atomic Energy Agency (IAEA) (Brown and Kaplow 2014; Fuhrmann 2009). Providers of civilian nuclear assistance are careful to avoid aiding in weapons efforts, but nuclear technology is inherently dual-use. Even seemingly benign forms of aid—general physics instruction, for example, or training in agricultural or medical applications of nuclear technology—can help to build expertise that translates to weapons work. As the A.Q. Khan network has shown, even sensitive technology is frequently available on the open market (Fitzpatrick 2007), and the number of potential suppliers has been increasing over time (Braun and Chyba 2004). Each of these forms of assistance reduces the ultimate cost of a weapons effort, encouraging states that might otherwise have been resource constrained to push forward with nuclear development. Perversely, the sheer availability of nuclear assistance also makes each individual cooperation agreement or nuclear aid project less important to the decision to begin a nuclear weapons effort.

Third, and partly because of the widespread availability of nuclear knowledge and foreign assistance, almost no state would now begin a nuclear weapons program from scratch. Most would-be proliferants can draw upon indigenous resources such as uranium deposits or a pool of experienced scientists and engineers. Many states have achieved a kind of nuclear latency—the underlying capacity to produce nuclear weapons—by virtue of their civilian nuclear power programs or academic research efforts.[12] These existing facilities and resources provide a useful base from which to launch a broader weapons program, and again alter the calculus for the decision to pursue weapons.

Finally, one way in which supply side factors encourage nuclear proliferation is by reassuring states about their chances of proliferation success. Given the potential negative consequences of nuclear weapons development, states will pursue weapons only if they feel they have a good chance of reaching the finish line. The more difficult nuclear weapons development seems, the less likely are states to start a program. Early nuclear weapons programs appeared less likely to end in success. Prior to the Manhattan

[12] For a useful introduction to the concept of nuclear latency, see Sagan (2010). For an attempt to measure nuclear latency more precisely, see Fuhrmann and Tkach (2015). Kaplow and Gibbons (2015) discuss nuclear latency in the context of the recent nuclear agreement with Iran.

Project, of course, it was not clear that a weapon *could* be developed successfully. Nobel Prize-winning physicist Hans Bethe, who later made significant contributions to the US nuclear effort, recalled that he at first "considered … an atomic bomb so remote that I completely refused to have anything to do with it. … I thought we would never succeed in any practical way" (Rhodes 1986, 415).

Even after the US program and other early efforts demonstrated a weapon was possible, the task still appeared quite difficult. The first nuclear weapons states devoted tremendous resources to their nuclear development efforts. At its peak, for example, the US nuclear weapons program during World War II employed about 125,000 people, with some 500,000 working for the Manhattan Project at some point during the war; the Soviet program employed a similar number (Wellerstein 2013). The size of these undertakings might be expected to deter all but the most technically capable states from launching nuclear weapons programs. Why expend the resources and risk international opposition when the successful development of a nuclear weapon seems so unlikely?

Later nuclear programs, however, have had the examples of China, Israel, India, South Africa, Pakistan, and North Korea to draw from. Pakistani Prime Minister Zulfikar Ali Bhutto famously said in 1965 that if India develops nuclear weapons, "even if we have to feed on grass or leaves—or even if we have to starve—we shall also produce an atom bomb" (Khan 2012, 6). States evaluating their own prospects for success today are likely to see weapons as more attainable, regardless of their own capabilities, than did potential proliferants in the 1950s and 1960s.

Together, these arguments suggest the following hypothesis:

> *Supply hypothesis: The effect of supply-side factors on nuclear proliferation has decreased over time.*

Nuclear motives

The motivation for nuclear proliferation ultimately reflects a state's perception of the usefulness of nuclear weapons for its own security. If leaders believe that acquiring nuclear weapons will translate into better odds of regime survival, they will be more likely to seek weapons. If leaders see nuclear weapons as neutral or as diminishing national security—for example, by inviting preemptive attack—they will be less likely to seek weapons.

It may be that nuclear weapons were viewed as more essential for state security early in the nuclear age, or at least during the Cold War. In the immediate aftermath of World War II—and without an established nuclear taboo (Tannenwald 2007)—states saw nuclear weapons as potentially useful in conflict. And under the shadow of nuclear threats from the United States or Soviet Union, at least some states believed the acquisition of a nuclear deterrent of their own was the only way to guarantee their security. Since the end of the Cold War, however, many view the utility of nuclear weapons as significantly diminished. Nuclear deterrence, in particular, has receded as a security imperative for many states, to the extent that most nuclear weapons states have been willing to pare down their own arsenals considerably (Norris and Kristensen 2010). This logic suggests the following hypothesis:

> *Demand hypothesis I: The effect of demand-side factors on nuclear proliferation has decreased over time.*

If the end of the Cold War brought a reduced risk of a great-power nuclear exchange, it also introduced a loosening of the entrenched alliance system from earlier in the nuclear age. The US and Soviet spheres of influence had formed the basis for many security commitments during the Cold War, some of which had been effective in limiting demand for nuclear weapons among key allies. The extended deterrence promise offered by the US nuclear umbrella, for example, seemed more credible in the context of superpower rivalry. States that would have been satisfied by alliance commitments in the past may now see a need to develop their own nuclear deterrent.

At the same time, nuclear weapons development seems like a sensible response to the general increase in the number of nuclear states and nuclear aspirants over time. As more states have investigated nuclear weapons efforts, and still more have built up a level of indigenous capability that could speed the path to the bomb if they decide to seek it, others may decide to follow suit. This may be because of particular concern about the programs or capabilities of neighbors and potential rivals—as posited by nuclear domino theories (Allison 2005; Miller 2014a), or just a general response to the changing threat environment.

These arguments suggest the following hypothesis:

> *Demand hypothesis II: The effect of demand-side factors on nuclear proliferation has increased over time.*

International institutions

Formal international institutions focusing on the spread of nuclear technology did not exist before the IAEA was formed in 1957 and did not seek to restrict nuclear weapons proliferation until the NPT entered into force in 1970. It may seem obvious, then, that the effect of international institutions on state proliferation decisions would be greater now than at the beginning of the nuclear age.

A number of analysts, however, see the NPT in particular as a weak institution that has little effect on state behavior.[13] Detailed case studies of nuclear restraint—the decisions of high-risk states to forgo weapons—have found little role for the NPT (Campbell, Einhorn, and Reiss 2004; Reiss 1995). Many argue that the NPT is in crisis, and that whatever constraining power it once had is now eroding (Perkovich 2006; Sauer 2006; Williams and Wolfstahl 2005). At least one analyst suggests that the NPT is likely to do more harm than good in the future (Wesley 2005). For these scholars, the NPT has lost whatever power it held in the early days of the nonproliferation regime, suggesting the following hypothesis:

> *Institutions hypothesis I: The effect of membership in the nuclear nonproliferation regime on nuclear proliferation has decreased over time.*

It may be, on the other hand, that the regime has actually increased its constraining power over states since its inception. What was once a few isolated treaties has evolved over time into a full regime complex, with a dense network of dozens of agreements, conventions, and informal institutions governing multiple dimensions of nuclear security and proliferation (Carcelli et al. 2014). The NPT and related institutions help to change the calculus for proliferant states in two ways.

First, the nonproliferation regime has increased the cost over time for states that pursue nuclear weapons. One way that the NPT constrains state behavior is by providing

[13] Some theorists in the realist tradition see international institutions like the NPT as largely epiphenomenal (Mearsheimer 1994).

information and a focusing mechanism for enforcement and punishment. As more states join the NPT and other aspects of the regime, this function of the treaty becomes more effective. Since nearly all non-nuclear states are now members of the NPT, states that seek to proliferate in the future will also be in violation of their international commitments, drawing enhanced scrutiny from the international community and increasing the chance of multilateral sanctions or other collective punishment.[14]

Second, the seeming effectiveness of the nuclear nonproliferation regime over time helps to reduce the motivation for nuclear pursuit among its members.[15] State parties to the NPT might initially worry that their commitment to forgo weapons development will not be reciprocated. Over time, however, the treaty has demonstrated its effectiveness. No state has successfully acquired weapons while a member of the NPT, and those states that have been thought to be seeking weapons within the treaty—Iran, for example—have seen a coordinated response from the international community. The regime's track record has helped to build confidence in its members that they need not seek weapons of their own.

This logic suggests the following hypothesis:

Institutions hypothesis II: The effect of membership in the nuclear nonproliferation regime on nuclear proliferation has increased over time.

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[14] Newly independent South Sudan is the lone state without nuclear weapons that has not yet joined the NPT.

[15] The NPT and associated institutions may also have been integral in instantiating over time an international norm of nonproliferation. On nonproliferation norms, see Rublee (2009).

Nuclear Proliferation Pathways

While there is a large international relations literature on the drivers of nuclear proliferation, few social scientists have addressed *how* states go about developing nuclear weapons. In a notable exception, Narang (2017) offers a typology of possible strategies of proliferation employed by states seeking at least a future nuclear option. Narang associates each strategy with a set of technical decisions by states, arguing that strategic choices dictate a particular technical path to a weapon. For example, a "sprinting" strategy emphasizes speed, and states pursuing this strategy will therefore develop nuclear facilities that are explicitly for military use. A "hiding" strategy, on the other hand, leads to secret facilities that are more easily concealed. Narang does not address, however, the possibility that the optimal technical choices for a particular strategy may change over time. "Hiding" states, for example, may find that overt facilities—rather than smaller, secret nuclear sites—are the best way to conceal the existence of a nuclear weapons program.

A related literature examines the link between civilian nuclear capability and nuclear weapons pursuit. Concerns about whether nuclear power would spur nuclear proliferation date back to the very beginning of the nuclear age. Studies of civilian nuclear assistance—both nuclear cooperation agreements between states and multilateral nuclear assistance from the IAEA—show that this assistance is associated with an increased likelihood of nuclear weapons pursuit (Brown and Kaplow 2014; Fuhrmann 2009, 2012). Nuclear power itself, however, does not appear to lead to nuclear proliferation in most cases (Miller 2017).

Though long a concern of scholars and analysts (Wohlstetter 1976), the literature recently has renewed its focus on latent nuclear capability—the capacity to produce nuclear weapons quickly if the decision is made to do so. Leveraging new data on the subject (Fuhrmann and Tkach 2015; Smith and Spaniel 2018; Spaniel 2019), scholars have examined what factors lead to increased nuclear latency (Mehta and Whitlark 2017b), and how nuclear latency can affect international outcomes of interest (Mehta and Whitlark 2017a; Spaniel 2019; Volpe 2017). This literature represents an important step in disaggregating nuclear capability, treating nuclear proliferation as more than just the presence or absence of nuclear weapons.

An applied literature uses the tools of decision analysis and technical assessments of fissile material production costs to better understand how states will go about seeking weapons (Ahmed and Husseiny 1982; Heising 1982; Silvennoinen and Vira 1981, 1986). The goal of much of this work was to develop more proliferation-resistant nuclear energy technology, but the technical pathways literature also offered a number of policy recommendations for those interesting in limiting the spread of nuclear weapons. This work has played an important role in developing the inspection approaches used by the IAEA to verify existing nuclear facilities in a state and to monitor potential diversion of nuclear material for military purposes (Anzelon et al. 2014; Kim, Renda, and Cojazzi 2015).

Nuclear pathways

States can acquire nuclear weapons in a number of ways. Pathways analysis has traditionally focused on three major factors that determine the route to a nuclear weapon: the choice of fissile material, the ability to acquire nuclear weapons technology from foreign suppliers, and the use of secret or overt nuclear facilities.

Nuclear weapons require either highly enriched uranium (HEU, containing a high percentage of uranium-235) or plutonium. HEU is produced by mining uranium ore, processing the ore into yellowcake (uranium ore concentrate), converting yellowcake into a form suitable for enrichment, and then increasing the concentration of the uranium-235 isotope through one or more of several possible enrichment processes. Plutonium is created in nuclear reactor fuel, usually fed by natural or low enriched uranium, then separated from the fuel through chemical reprocessing. A state's decision to use highly enriched uranium or plutonium for its first nuclear weapons helps determine the types of facilities it will need, the size of its nuclear infrastructure, and its ability to conceal this infrastructure from other states (Ullom 1994).

Outside assistance can substantially influence a state's pathway to a nuclear weapon. At one extreme, the acquisition of a completed nuclear device from a weapon state—whether willingly given or illicitly smuggled—may obviate the need for the development of any nuclear infrastructure at all. There has been speculation, for example, that Pakistan might be willing to provide Saudi Arabia with a nuclear weapon should Iran ultimately acquire a nuclear capability (Hoodbhoy 2015). States may also seek to acquire from abroad highly enriched uranium or plutonium, leaving only weaponization to be completed indigenously.[16] States frequently have acquired full

[16] There is a clear trade-off between taking advantage of foreign assistance pathways to nuclear weapons development and the ability to field a large nuclear arsenal. Acquisition of a single weapon or enough fissile material for a small number of weapons is plausible,

fissile material production facilities—including enrichment plants, nuclear reactors, and reprocessing facilities—from nuclear suppliers, easing the path to the development of nuclear infrastructure. This assistance has sometimes been intended by the supplier to spur weapons work—as was likely in the case of the North Korean-built nuclear reactor in Syria, for example (Office of the Director of National Intelligence 2008)—but more frequently has been provided under at least the plausible cover of civilian nuclear research or power infrastructure (Fuhrmann 2008; Kroenig 2009a). Foreign assistance with technology development can ease the path to building indigenous nuclear infrastructure, leading states to pursue particular pathways to a weapons capability. The AQ Khan network, for example, offered or provided centrifuge technology and other sensitive information to a number of states, including Iraq, Iran, and Libya (Braut-Hegghammer 2016; Fitzpatrick 2007).

Finally, because of the dual-use nature of nuclear technology, states seeking weapons face a choice between using secret facilities or repurposing civilian infrastructure for nuclear weapons development.[17] States may adopt a fully covert fuel cycle, using secret facilities to enrich uranium or to produce and reprocess plutonium. The early nuclear weapons states fall into this category; the presence of nuclear sites in

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if unlikely. Larger quantities of material almost certainly would require a separate nuclear infrastructure, absent a cooperative production arrangement with a supplier state.

[17] Civilian nuclear sites are usually, but not exclusively, associated with a nuclear power program. A large number of states also possess facilities designed for research and technology development or the production of radioisotopes for medical or agricultural applications.

the US and Soviet Union during the 1940s and 1950s were considered state secrets. More recently, states such as Iraq, Libya, and Syria have pursued weapons programs covertly. States also may produce fissile material for a weapon entirely at sites declared to be part of a nuclear power program. India, for example, used a Canada-supplied power reactor to produce fissile material used in its 1974 test of a nuclear device. An overt nuclear infrastructure enables both a *hedging* strategy, in which the state maintains the option for weapons development in the future (Levite 2003; Narang 2017), and a *breakout* strategy—the use of declared facilities to produce fissile material for a weapon, without regard for the risk of detection. Alternatively, states may employ a mix of these two approaches—a *diversion* strategy—for example by producing low-enriched uranium at a declared site associated with a civilian power program, then further enriching that material to weapons grade at a secret facility.

It is this last factor—the choice of overt or covert facilities for fissile material production—that I will focus on here. The overt versus covert decision touches on a central tradeoff faced by would-be nuclear weapons states between speed and secrecy. Pursuing a covert nuclear infrastructure is likely to slow nuclear development for several reasons. First, there is the basic physics of fissile material production. All else equal, larger facilities can produce more material more quickly than smaller sites, but of course larger facilities are also more easily detected.

Second, covert programs are likely to advance more slowly because the pool of technical expertise and resources are necessarily limited by the requirements of secrecy. Civilian nuclear development can draw on experts from the private sector, research institutions, government agencies, and even foreign companies, but secret programs typically rely on a much smaller cohort of technical experts who can be vetted for work on military programs. In a similar vein, covert programs have a smaller set of possible foreign suppliers who will be willing to contribute to the program's development. Nuclear programs that at least maintain the appearance of civilian research or nuclear power goals can plausibly receive assistance from the full range of nuclear suppliers.[18]

Third, the need for secrecy may dictate technical choices that extend nuclear timelines or even make successful nuclear weapons acquisition less likely. Covert programs, for example, might focus on gas centrifuge uranium enrichment—because centrifuge facilities have few external signatures and can be more easily concealed—when a plutonium production reactor would be a more expeditious pathway to weapons-usable fissile material.

In some cases, pursuit of a particular nuclear outcome may demand the use of overt or secret nuclear sites. For example, states that are undecided about whether to pursue a weapons capability, and that simply want to maintain the option to do so in the future, may naturally seek a hedging strategy that emphasizes civilian nuclear infrastructure. But in other cases, more than one pathway to a weapon could plausibly address a state's strategic goals.[19] In these situations, what leads states to choose one

[18] Foreign supply may not always speed nuclear development, although governments tend to behave as if it does. See Montgomery (2013).

[19] This approach contrasts with Narang's (2017) framework, which links particular strategies of proliferation to particular technical decisions—such as whether to use overt or covert facilities.

pathway over the other? States weigh the relative costs of each pathway against its benefits. We can simplify this calculus to three broad factors that influence the decision to choose overt facilities or covert facilities for fissile material production: the risk that a covert nuclear weapons effort will be detected, the consequences of this detection, and the relative benefit of a weapon developed via a particular pathway. Changes in these factors make the use of a covert nuclear infrastructure more or less attractive to states.

The greater the chance that a secret nuclear weapons effort will be detected by outside actors—be it an adversary or international inspectors—the more likely a state is to pursue a declared, civilian nuclear infrastructure. Why trade speed for secrecy if covert activities are likely to be discovered regardless? The risk of detection also factors into decisions about whether to divert material from civilian facilities. In most cases, diversion seems more likely to be detected than the presence of covert facilities, simply because international safeguards regimes focus most of their efforts on inspecting declared sites. As the risk of detection increases, diversion scenarios, too, become less attractive than a full breakout scenario.

The consequences states are likely to face if they are detected with a covert weapons program also factor into state decision-making. When the likelihood and severity of a potential punishment for covert nuclear pursuit is high relative to overt pathways, a state is more likely to focus attention on its civilian nuclear infrastructure. Both covert and overt pathways offer opportunities for the international community to punish nuclear weapons pursuit, so an important factor here is the window during which outside actors might take action against the proliferant state. States using an overt nuclear infrastructure may reduce this period of vulnerability by getting as close as possible to producing fissile material for a weapon before attempting work that is clearly linked to nuclear weapons development. This is because acquisition of a nuclear weapons capability makes severe punishment from the international community much less of a risk—no nuclear weapons state has been targeted with an attack on its nuclear facilities (Fuhrmann and Kreps 2010). The shorter this breakout timeline is assessed to be, the more attractive is an overt approach relative to the use of secret facilities.

In addition to these differing costs, one pathway might offer benefits over the other. As suggested above, speed is one oft-cited tangible benefit of an overt approach. Although it has not always worked this way in practice (Miller 2017), states might well expect that the ability to operate openly would lead to an advanced nuclear infrastructure much more quickly than an effort that required secrecy. The size of nuclear facilities, too, might make one pathway more desirable than another. States that are eager to produce a large nuclear arsenal might require a more substantial infrastructure—perhaps more than could reasonably be kept secret—than states that are satisfied with a handful of nuclear weapons. And states may also value the flexibility offered by overt sites; leaders can always switch to a hedging strategy or abandon nuclear weapons ambitions without having to justify wasted resources on facilities that cannot be repurposed.

A theory of change in nuclear proliferation pathways

Analysts and scholars have long assessed that nuclear aspirants would be more likely to take advantage of covert pathways to a nuclear weapon than to seek a nuclear breakout using civilian infrastructure. The logic of this assessment is straightforward. Diversions from overt facilities or the use of declared facilities themselves to produce fissile material for a weapon would be more likely to be detected by outside actors than similar activity at a covert site (Einhorn 2006). Given the consequences of discovery, states are most likely to focus on covert pathways. The US intelligence community made this judgment explicit and public in the case of Iran, writing in the Key Judgments to a 2007 National Intelligence Estimate, "We assess with moderate confidence that Iran probably would use covert facilities— rather than its declared nuclear sites—for the production of highly enriched uranium for a weapon" (National Intelligence Council 2007).

It may be time, however, to revisit this assessment. While states are likely to vary in their calculus of the risks and rewards of secret weapons efforts, broader changes in the dynamics of nuclear proliferation seem to have made the use of overt facilities generally more attractive over time, and especially for potential future nuclear aspirants. Below, I reexamine each of the factors that influence the choice between overt and covert pathways—the risk of detection, the consequences of detection, and the relative benefits of the overt pathway—to identify how these factors have shifted over time.

The risk of detection

The chance that an undeclared nuclear facility will be detected has increased substantially over time, making covert pathways less attractive to would-be nuclear weapons states. An important driver of this change has been the continuing evolution and strengthening of nuclear safeguards. The most significant changes in nuclear monitoring and verification measures have come in three areas: in the fundamental approach to nuclear safeguards, in the technologies and procedures employed to verify safeguards compliance, and in the scope of coverage of nuclear facilities and materials.

Before the NPT came into force in 1970, IAEA safeguards were generally implemented piecemeal on select nuclear facilities within a country, usually as a condition of sale specified by the nuclear supplier (Jennekens 1990). Under the NPT, member states were required to implement comprehensive or full-scope safeguards, which place all nuclear material in the country under IAEA purview. The need for full-scope safeguards was emphasized by India's 1974 nuclear test, which used nuclear material that had been diverted from civilian facilities provided by the United States and Canada (Tape and Pilat 2008). The resulting safeguards approach of the 1970s and 1980s focused on the verification of state declarations and ensuring that no nuclear material had been diverted from a safeguarded facility (Carlson et al. 1999; Gruemm 1983). The underlying safeguards philosophy shifted again in 1991 with the discovery that Iraq had harbored an extensive nuclear weapons program despite having full-scope IAEA safeguards in force.[20] Rather than focus solely on the verification of state declarations to the IAEA, the mission of safeguards inspectors was expanded to address the completeness of declarations and the possibility of undeclared nuclear activities (Carlson et al. 1999; Goldschmidt 2001; Pellaud 2000; Tape and Pilat 2008).

[20] On Iraq's nuclear weapons efforts, see Braut-Hegghammer (2016).

The Iraq revelations also drove the introduction of new technologies and procedures into safeguards practice. Unattended monitoring systems, for example, saw substantial improvements. The IAEA in the 1970s monitored spent fuel pools using a pair of cameras set to shoot every twenty minutes. Inspectors would attempt to review thousands of black-and-white images at every visit, looking for any sign that the spent fuel had been moved. In the last twenty years, however, the IAEA has deployed more advanced unattended monitoring systems. Today's systems can capture radiation and other measurements as well as images, and in some cases are monitored remotely (Schanfein 2008). While the IAEA has always benefited from satellite imagery provided directly from member states, only recently has it gained the capability to independently order and analyze commercial satellite imagery in support of safeguards goals (Chitumbo, Robb, and Hilliard 2002). Access to satellite imagery is particularly important to identifying suspected undeclared facilities that might merit further investigation (Ferguson and Norman 2010).

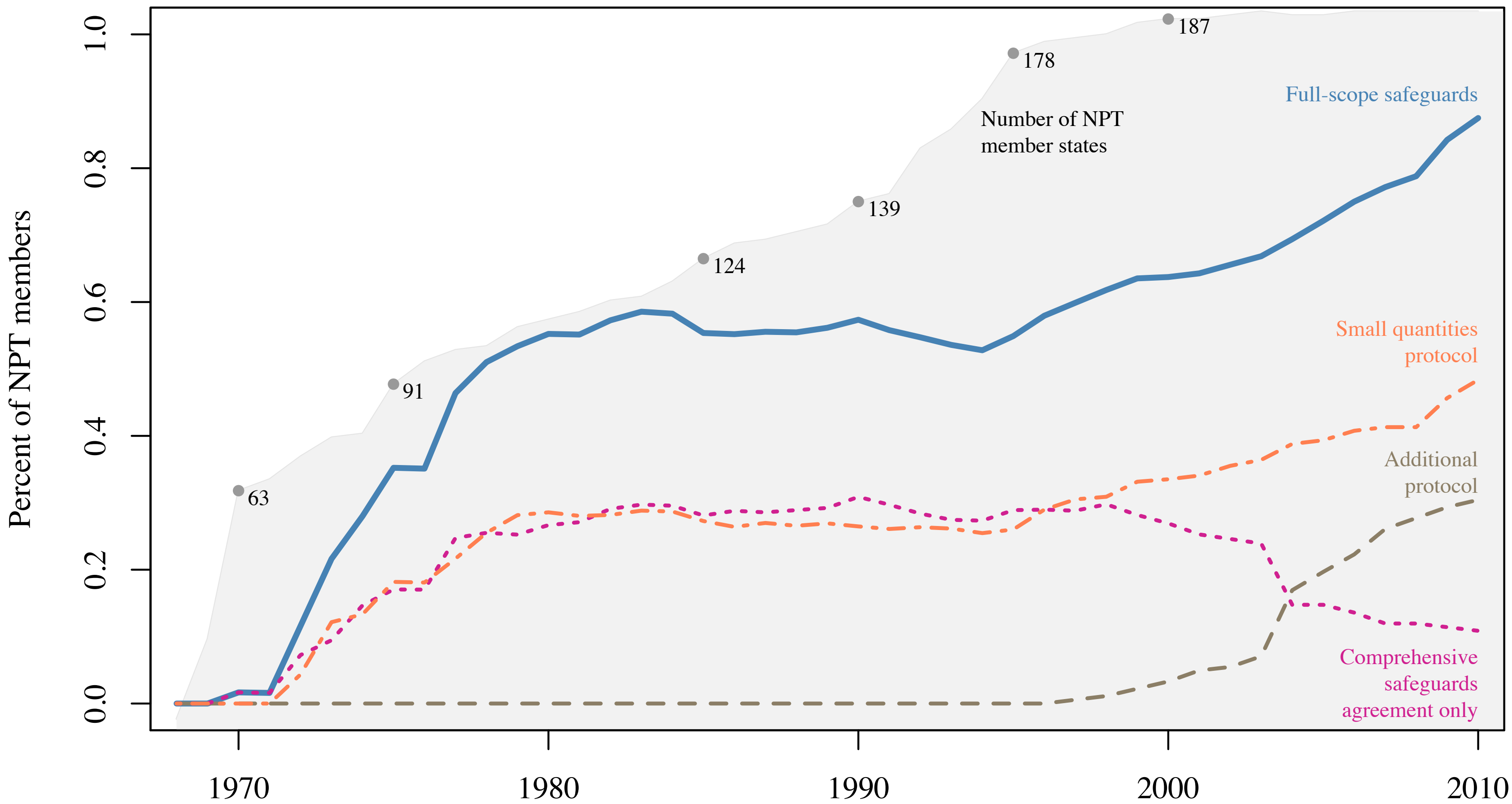
Environmental sampling techniques were introduced to IAEA safeguards in the mid-1990s, allowing IAEA inspectors to measure the isotopic composition of nuclear materials, potentially contradicting a state's declarations (Donohue 1998; Donohue, Deron, and Kuhn 1994). Environmental sampling played an important role in building the noncompliance case against Iran. Agency inspectors in 2003 requested access to a suspected, but undeclared, centrifuge workshop. Iran eventually allowed inspections, but only after an attempt to decontaminate the facility—replacing the floor, repainting walls, and moving equipment to other locations. Still, environmental sampling there detected enriched uranium particles that could not be explained by Iran's existing declarations and led to Iran's acknowledgment later that year that it had indeed conducted undeclared centrifuge testing at the facility using nuclear material (Samore 2005).

Safeguards technologies like environmental sampling are only useful if the IAEA has access to nuclear facilities. Such access is granted by means of a comprehensive safeguards agreement between the state and the IAEA. The NPT calls for these agreements to enter into force within 18 months of joining the treaty, but the actual performance of member states in this area has been far worse.[21] Figure 2.1 shows safeguards adoption over time as a percentage of NPT member states in a given year. The solid line indicates the presence of full-scope safeguards from a comprehensive safeguards agreement of any type. As recently as 1995, only 55 percent of NPT member states had a comprehensive safeguards agreement in force, although total adoption had risen to 87 percent by 2010 (Carcelli et al. 2014).

Figure 2.1 highlights three categories of full-scope safeguards. A comprehensive safeguards agreement grants the IAEA access to nuclear facilities for the purposes of verifying state declarations about nuclear activities. Beginning in 1997, as a response to the undeclared nuclear activities in Iraq, NPT member states were encouraged also to bring into force an Additional Protocol to their safeguards agreement that provides the

[21] This requirement applies only to non-nuclear weapons state parties to the NPT. While the P5 nuclear weapons states (China, France, Russia, the United Kingdom, and the United States) have voluntarily implemented safeguards and allowed inspections at some facilities, these are not full-scope safeguards that cover every nuclear facility within the state.

Figure 2.1: Adoption of full-scope safeguards by NPT member states over time



IAEA with wider access to verify the completeness of state declarations. This includes the requirement to declare nuclear facilities and allow inspections there even when nuclear material is not present, and the wider use of environmental sampling to provide assurances that nuclear material has not been introduced at undeclared sites (Hirsch 2004).[22]

If the Additional Protocol represents a more stringent level of safeguards access than a standard comprehensive safeguards agreement, then the Small Quantities Protocol (SQP) is a significant step down.[23] For states with quantities of nuclear material below a particular threshold, the SQP reduces declaration requirements and limits IAEA access to facilities within the state. Importantly, there is no mechanism by which the IAEA can seek to verify the state's assertion that it meets the requirements for the SQP in the first place. This represents an enormous loophole in the safeguards system—the IAEA must trust that a state is correctly characterizing its low level of nuclear development and must rely on the state to notify the IAEA when these conditions no longer apply.[24] The IAEA in 2005 took steps to close this loophole with a modified version of the SQP

[22] On the importance of the Additional Protocol for limiting proliferation generally, see Schulte (2010).

[23] The Additional Protocol and Small Quantities Protocol are not mutually exclusive. In 2010, 44 NPT member states had both protocols in force. The SQP places limits on IAEA action even when an Additional Protocol is also present, for example waiving the requirement that states provide initial declarations of nuclear materials and activities (Kerr 2005b)

[24] No state has been found to be using the SQP as part of a clandestine nuclear weapons effort. Still, the decision of states like Saudi Arabia to adopt the SQP rather than a standard comprehensive safeguards agreement has aroused suspicion (Kerr 2005b; Perkovich 2008).

that allows the IAEA to verify state declarations and, if necessary, conduct in-country inspections (International Atomic Energy Agency 2005b; Kerr 2005a, 2005b).[25]

Overall, the trend in safeguards coverage has been positive, especially since the mid-1990s. Almost all states now have some type of full-scope safeguards agreement in place. After a slow start, a substantial number of states have signed the Additional Protocol, granting the IAEA new tools in its efforts to verify compliance. The introduction of a modified SQP effectively closes the largest remaining loophole in the safeguards system for states that bring the modifications into force. This increased access, combined with a new approach to inspections that makes use of new technologies and procedures, suggests that IAEA safeguards are significantly more formidable today than in decades past.

Another important determinant of the risk that covert nuclear weapons efforts will be detected is the growth in NPT membership over time (the shaded portion of Figure 2.1). Not only have IAEA safeguards become more effective, but the increase in NPT membership occurring at the same time has made far more states subject to these full-scope safeguards measures. One clear result of the growth of NPT membership is that the IAEA now has substantially more access to nuclear facilities in more states than at any point in the history of the regime. And because nearly any future proliferant would be seeking nuclear weapons as an NPT member state—among non-weapons

[25] Then-IAEA Director-General Mohammed El-Baradei recommended eliminating this type of safeguards agreement altogether, but his proposal was not accepted by the IAEA's Board of Governors (Kerr 2005a).

states, only newly independent South Sudan has not signed the treaty—states will need to adjust their strategy to contend with this greater risk of detection from the beginning of the program.

Changes in the strength of verification measures and in NPT membership suggest the following hypothesis:

> *Risk of detection hypothesis: The likelihood that a covert nuclear weapons effort will be detected by the international community has increased over time.*

The consequences of detection

The allure of the covert pathway to weapons is that it allows a state to develop a nuclear weapons capability without permitting adversaries or the international community a chance to respond. One element of the cost of this pathway is the risk that the covert activity is detected; the other is the consequences that the state will bear if its actions are found out before they bear fruit. While the NPT itself lacks formal power to punish violators—a finding of noncompliance with the NPT merits merely a referral to the UN Security Council, for further action at its discretion—the international community does frequently act in a variety of ways to pressure states to stop weapons development efforts. Enforcement tools available to states range from unilateral attempts at persuasion, to global sanctions regimes like those arrayed against Iran and North Korea in recent years, to preemptive military attack.

Empirical studies of nuclear sanctions and other counterproliferation measures highlight some ups and downs, but the pattern broadly points to more reliable punishment over time. The use of nuclear sanctions first emerged as a prominent tool of US foreign policy in the 1970s (Miller 2014b). Reynolds and Wan (2012) track 454 sanctions and positive inducements employed against Iraq, Iran, Libya, and North Korea since 1990, finding that sanctions have largely leveled off since the 1990–1994 period, while positive inducements spiked in the late 1990s and have declined since.[26] Fuhrmann and Kreps (2010) identify 21 dyad-years in which attacks against nuclear facilities occurred between 1941 and 2000. Following a number of attacks on nascent nuclear facilities in Germany during World War II, strikes peaked in the 1980s and 1990s, largely targeting Iraq.[27] To this tally we can add at least Israel's strike against a Syrian nuclear reactor in 2007.

The trend in sanctions and other enforcement behavior, however, is necessarily related to the prevalence of nuclear pursuit; only when states are seen as seeking weapons can their behavior be punished. Since 1990, all non-weapons states with active nuclear weapons programs—Libya, Iraq, Iran, North Korea, and Syria—have been subjected to severe international sanctions designed to curb nuclear progress, military attack, or both. There can no longer be much doubt for proliferant states that the international community is likely to take strong action against covert nuclear weapons work, if such work is discovered.

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[26] As Reynolds and Wan (2012) point out, some of this trend can be explained by the removal of Iraq and Libya as sanctions targets by the early 2000s.

[27] Israel's strike on Iraq's Osirak reactor in 1981 may have played a particular role in driving the Iraqi program from primarily overt to primarily covert. See Braut-Hegghammer (2011)

Of course, attempts to use overt facilities to produce weapons are also likely to be discovered and punished.[28] But a state can mitigate the effect of this punishment by limiting the amount of time it is vulnerable to sanction or attack before it has acquired a weapons capability. States pursuing overt pathways to a nuclear weapon will seek to minimize the breakout time between a shift to weapons work and actual production of a nuclear weapon. There is some reason to believe that this window of vulnerability has narrowed over time, and that this trend has recently become more apparent to states.

In the early years of the nuclear nonproliferation regime, a number of states contemplated a hedging strategy which would bring them close to a weapons capability using overt facilities. But it was not clear how close these states would be able to get to weapons work before their actions would be seen as suspicious or problematic by the international community. Australia, for example, assessed before signing the NPT that the treaty would allow it to get within 3 years of a nuclear weapon (Australia Department of Defence 1968).

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[28] It is worth noting that the ability of the IAEA to detect diversion from large nuclear facilities has been repeatedly called into question. This problem may be getting worse, as a limited pool of IAEA inspectors is called upon to safeguard larger and larger nuclear sites. Sokolski (2008) points out that the IAEA was responsible for inspecting six times the amount of weapons-usable plutonium and highly enriched uranium in 2004 than it was in 1984, but that the Agency's budget barely doubled in real terms. And it is not at all clear that the IAEA can detect diversion of material in a safeguarded facility with enough lead-time to allow for diplomatic efforts to stop nuclear weapons acquisition. "In fact, there is insufficient time [for] the IAEA staff to develop its report to the Board of Governors of the IAEA and for the Board of Governors to report to the UN Security Council." (Cochran 2008).

But if there had been any doubt remaining, the case of Iran made it quite clear that overt facilities could bring a state to within months or even weeks of a weapon's capability. By 2015, at the time of its agreement with world powers to limit its nuclear development, Iran had a substantial nuclear infrastructure in place. Its major nuclear sites included uranium mines and production facilities at Gachin, Saghand, and Ardakan; a uranium conversion facility and fuel manufacturing plant at Esfahan; uranium enrichment plants at Natanz and Qom; a research reactor in Tehran; a heavy water production facility and reactor at Arak; and a nuclear power reactor at Bushehr; among many other subsidiary and support facilities.[29] Experts assessed before the agreement that Iran could use these facilities to produce enough fissile material for a nuclear weapon in 2–3 months (The White House 2015).[30] Of course, Iran paid a substantial price for its nuclear development. Years of escalating sanctions had taken a toll on Iran's economy and contributed to Tehran's political isolation from the rest of the world.

But the international community's response to Iranian nuclear development was not a foregone conclusion. It hinged on a key development—the finding by the IAEA's Board of Governors in 2005 that Iran was in noncompliance with its commitments under the NPT (International Atomic Energy Agency 2005a). And the basis of this finding was not Iran's development of nuclear facilities alone, but rather its failure to declare these

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[29] For a discussion of major nuclear sites in Iran, see Nuclear Threat Initiative (2017).

[30] A major US goal in negotiations with Iran was to extend that breakout time to at least a year while the agreement was in force (The White House 2015). On whether breakout time alone is an appropriate metric for judging the Joint Comprehensive Plan of Action, see Kaplow and Gibbons (2015) and Vaez (2015).

facilities to the IAEA. In the Iranian case, the cover-up was worse than the crime: Iran's nuclear infrastructure was in keeping with its NPT commitments, but its secrecy about those facilities was not. Iran would have faced strong pressure to limit its nuclear development in any case, but its failure to declare its nuclear facilities directly facilitated broad-based international sanctions that would have been difficult to achieve in the absence of a clear violation of its safeguards agreement.

Future nuclear aspirants might draw the lesson from this case that it is possible for states to acquire a latent nuclear weapons capability while still abiding by their NPT commitments. Iran was punished for its secrecy, but other states might simply declare their nuclear facilities in accordance with IAEA procedures and reap all the benefits of a full overt nuclear infrastructure. To the extent that the Iran case demonstrates that very short breakout timelines are possible, this makes overt pathways to a weapon more compelling to potential proliferants.

This logic suggests the following hypothesis:

> *Consequences of detection hypothesis: The perceived costs that a state will incur if its nuclear weapons effort is detected has increased over time.*

The relative benefit of overt pathways

The risk and consequences of detection capture the cost states bear by choosing covert pathways to a bomb. There also has been a shift, however, in the relative benefit of overt facilities versus secret alternatives. Because of changes in foreign nuclear supply, overt pathways in recent years may have become more likely than covert efforts to lead to advanced nuclear capabilities.

The nuclear nonproliferation regime itself has had an important deleterious effect on the provision of sensitive nuclear supply. In the early years of the nuclear age, nuclear weapons states did not hesitate to provide nuclear technology to allies explicitly nuclear weapons purposes (Kroenig 2010). The NPT prohibited weapons states from providing such assistance to non-weapons states. This provision was strengthened by the creation of the Nuclear Supplier's Group in the 1970s and the accession of longtime-holdouts France and China to the NPT in the 1990s. The result is that sensitive nuclear assistance from foreign suppliers is much harder to come by than in years past.[31] This dynamic tends to push proliferant states—especially those incapable of a fully indigenous nuclear development effort—toward overt facilities, where foreign supply is still a possibility.

States may also be placing increasing value on the flexibility offered by a hedging strategy that makes use of a civilian nuclear infrastructure. As international norms against the development of nuclear weapons have increased in strength over time with the broadening membership and substantive expansion of the nuclear nonproliferation regime (Knopf 2018; Rublee 2009), they may have become more likely to influence domestic debates about nuclear behavior (Cortell and Davis 1996). Given the widespread opprobrium that attends to nuclear weapons development, even leaders with strong nuclear weapons ambitions may have trouble assembling a domestic coalition in favor of a nuclear effort that is explicitly for weapons (Narang 2017). Selling key

[31] North Korea, assessed to be the primary supplier of Syria's covert nuclear reactor (Office of the Director of National Intelligence 2008), may be the exception to this general rule.

constituencies on a civilian nuclear infrastructure, at least as a first step, is potentially a much easier task.

These changes suggest the following hypothesis:

Relative benefit hypothesis: The relative benefit of overt versus covert pathways to a weapon has increased over time.

Implications for Nonproliferation Research and Policy

This chapter highlights a potential problem with empirical analyses of nuclear proliferation. Most research that seeks to identify the causes of proliferation—and particularly work taking a quantitative approach to empirical testing—assumes that the effects of particular drivers of proliferation remain constant over time. This is a strong assumption. I theorize, instead, that the importance of particular drivers of proliferation has shifted since the dawn of the nuclear age, as has the preferred means by states seek weapons. My theory suggests that supply-side factors—including state capacity and the ability to obtain nuclear assistance—figure less prominently in state decisions to pursue weapons today than in early weapons programs. The trajectory for demand-side drivers of proliferation and for the effect of international institutions is less clear, and I propose competing hypotheses in each of these areas that lays out the case for a stronger or weaker role over time. The same theorized changes in nuclear proliferation dynamics may have made overt pathways to nuclear pursuit more likely now than in the past. The hypotheses advanced in this chapter are summarized in Table 2.1.

Table 2.1: Hypotheses examined in this book

Proliferation drivers: Why states seek weapons	
Supply	The effect of supply-side factors on nuclear proliferation has decreased over time.
Demand I	The effect of demand-side factors on nuclear proliferation has decreased over time.
Demand II	The effect of demand-side factors on nuclear proliferation has increased over time.
Institutions I	The effect of membership in the nuclear nonproliferation regime on nuclear proliferation has decreased over time.
Institutions II	The effect of membership in the nuclear nonproliferation regime on nuclear proliferation has increased over time.
Proliferation pathways: How states seek weapons	
Risk of detection	The likelihood that a covert nuclear weapons effort will be detected by the international community has increased over time.
Consequences of detection	The perceived costs that a state will incur if its nuclear weapons effort is detected has increased over time.
Relative benefit	The relative benefit of overt versus covert pathways to a weapon has increased over time.

This more dynamic sense of the nuclear proliferation landscape is important both for future scholarship and for the ability of researchers to contribute to today's nonproliferation policy challenges. My theory, if correct, suggests that the commonly used approach in quantitative work of pooling all observations over time risks biasing our results. Scholars should instead look for empirical strategies that allow the effects of their variables of interest to change over time and should examine whether their findings hold up across different time periods within the data. Scholars should also be careful about applying results from the entirety of the nuclear age to address contemporary issues in nonproliferation policy. We would, of course, be cautious in applying lessons from the Manhattan Project to our analysis of Iran's contemporary nuclear program; we should recognize that some of our empirical results may stem from the same type of comparison.

The changing face of nuclear proliferation also has a number of implications for policymakers. Scholars and analysts have long worried about latent nuclear capabilities, but the nonproliferation community has not focused on several important implications of a world with more states on the verge of a weapons capability. Understanding the shifting proliferation landscape is essential to designing effective strategies for combatting proliferation, developing indicators of proliferation behavior, and assessing future proliferation risk.

The shift from covert to overt pathways complicates the task of analysts and scholars seeking to identify states of proliferation concern. The nonproliferation community has long relied on a variety of indicators of weapons intent—such as covert facilities, shadowy procurement activity, or the presence of weapons-usable materials—that we are unlikely to observe in a state that opts for an overt pathway to a weapon. Assessing proliferation risk in this environment will require a new set of probabilistic indicators of nuclear behavior, focusing on the broader political and security context rather than technical details. An increase in the prevalence of latent nuclear weapons capabilities also calls for a renewed emphasis on accurately evaluating breakout timelines given a particular set of overt capabilities.

Latent nuclear capabilities also place an additional burden on the IAEA-led nuclear inspection regime. The IAEA has steadily placed more and more emphasis on the presence of undeclared facilities in a state. While it is important to maintain this posture, the IAEA should also increase efforts to limit the gap between the start of breakout activities at safeguarded nuclear facilities and the time at which the IAEA becomes aware of these activities. The tools that will facilitate this shift are already available—unattended monitoring systems, more precise measurements to reduce material unaccounted for in nuclear plants, and rapid environmental sampling, for example—but these tools have not been made widely available for use in facilities that are not already considered a high priority.

IAEA inspectors also could better contribute to evaluating proliferation risk by providing the international community with more detail about potential breakout timelines. Currently, the major deliverable for the IAEA is the Agency's conclusion that all nuclear material in a state is being used for peaceful activities. But for a state with a latent nuclear capability, this conclusion is not particularly meaningful. States adopting an overt pathway to a weapon may be using all their material for peaceful activities and still be only weeks away from a weapons capability. A more useful deliverable in a world of nuclear latency would be a technical judgment about how close a state is to a weapons capability, and how quickly the IAEA would be capable of detecting any diversion or breakout attempt. The IAEA is uniquely positioned to provide that information to the broader nonproliferation policy community, although such a shift in emphasis would be likely to anger some member states.

Finally, the increasing prevalence of overt pathways to a weapon should shift the focus of institutional attention away from the NPT—which is poorly equipped to limit civilian nuclear capabilities—and toward other institutional arrangements, including bilateral agreements, that can more effectively place restrictions on nuclear supply. The NPT was designed with a guarantee of nuclear supply as one of its core pillars; one of the central bargains of the treaty trades nuclear forbearance on the part of non-weapons states for the provision of peaceful applications of nuclear technology. It is thus not surprising that states would be able to go right to the edge of nuclear weapons capability and still be in full compliance with their commitments under the NPT. Other institutions, however, such as the Nuclear Supplier's Group, are better positioned to put limits on trade in nuclear technology.

Better positioned still are the bilateral nuclear cooperation agreements that many recipient states enter into. These agreements—123 Agreements in the United States—are an effective way to designate some uses of nuclear technology as out-of-bounds, because they carry the immediate threat of cutting off nuclear cooperation if the rules of the agreement are not met. For example, the United States has previously insisted in its nuclear cooperation agreements that recipient states abide by the "gold standard" and agree not to engage in enrichment or reprocessing activities. This provision has not been adopted, however, in recent nuclear cooperation agreements.

Empirical testing of the hypotheses described above, and examining their implications, is the work of the remainder of this book. Chapter 3 looks at the predictive power of each of the drivers of proliferation, adapting a rolling-window cross-validation technique from the machine learning literature to construct a temporal map of how the determinants of proliferation have changed over time. Chapter 4 examines the trajectory of the three primary drivers of proliferation— capability, motivation, and international institutions—in more detail, using a medium-n analysis of nuclear aspirants. Chapter 5 discusses how countries approach weapons development, examining several cases that illustrate how preferred proliferation pathways have changed over time, and are likely to change in the future. Chapter 6 addresses the future of proliferation policy, deriving specific proposals to address the particular proliferation challenges the international community is likely to face over the next decade. The conclusion, Chapter 7, summarizes the arguments of the book and suggests several early indicators of future changes in proliferation trends.

References

Ahmed, Shahid, and A. A. Husseiny. 1982. "Risk Assessment of Alternative Proliferation Routes." *Nuclear Technology* 56(3): 507–515.

Allison, Graham. 2005. "The Cascade of Proliferation." *Atlantic Monthly* 296(3): 36–37.

———. 2010. "Nuclear Disorder: Surveying Atomic Threats." *Foreign Affairs* 89(1): 74–85.

Anderson, Christopher C., Sara McLaughlin Mitchell, and Emily U. Schilling. 2016. "Kantian Dynamics Revisited: Time-Varying Analyses of Dyadic IGO-Conflict Relationships." *International Interactions* 42(4): 644–76.

Anzelon, George, Kory Budlong-Sylvester, Chantel Murphy, and Celia Reynolds. 2014. *Prioritizing Acquisition Paths under the State-Level Concept*. Lawrence Livermore National Laboratory.

Australia Department of Defence. 1968. "An Independent Australian Nuclear Capability – Strategic Considerations." National Archives of Australia: A1946, 1967/1017 part 1, p87–110.

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

Braun, Chaim, and Christopher F. Chyba. 2004. "Proliferation Rings: New Challenges to the Nuclear Nonproliferation Regime." *International Security* 29(2): 5–49.

Braut-Hegghammer, Målfrid. 2011. "Revisiting Osirak: Preventive Attacks and Nuclear Proliferation Risks." *International Security* 36(1): 101–32.

———. 2016. *Unclear Physics: Why Iraq and Libya Failed to Build Nuclear Weapons*. Ithaca, NY: Cornell University Press.

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.

Campbell, Kurt M., Robert J. Einhorn, and Mitchell Reiss. 2004. *The Nuclear Tipping Point: Why States Reconsider Their Nuclear Choices*. Washington, DC: Brookings Institution Press.

Carcelli, Shannon, Erik Gartzke, Rebecca Gibbons, and Jeffrey M. Kaplow. 2014. "The Nuclear Regime Complex: A New Dataset." *Paper prepared for the 2014 International Studies Association Annual Convention, Toronto, Canada*.

Carlson, John, Victor Bragin, John Bardsley, and John Hill. 1999. “Nuclear Safeguards as an Evolutionary System.” *The Nonproliferation Review* 6(2): 109–17.

Central Intelligence Agency. 1964. *Prospects for a Proliferation of Nuclear Weapons Over the Next Decade*. National Intelligence Estimate. CIA FOIA Reading Room.

Chitumbo, K., S. Robb, and J. Hilliard. 2002. “Use of Commercial Satellite Imagery in Strengthening IAEA Safeguards.” In *Commercial Satellite Imagery: A Tactic in Nuclear Weapon Deterrence*, eds. Bhupendra Jasani and Gotthard Stein. Chichester, UK: Praxis Publishing Ltd., 23–48.

Cirincione, Joseph. 2008. *Bomb Scare: The History and Future of Nuclear Weapons*. New York, NY: Columbia University Press.

Cochran, Thomas B. 2008. “Adequacy of IAEA’s Safeguards for Achieving Timely Detection.” In *Falling Behind: International Scrutiny of the Peaceful Atom*, ed. Henry D. Sokolski. Carlisle, PA: Strategic Studies Institute.

Cortell, Andrew P., and James W. Davis. 1996. “How Do International Institutions Matter? The Domestic Impact of International Rules and Norms.” *International Studies Quarterly* 40(4): 451–78.

Donohue, David. 1998. “Strengthening IAEA Safeguards through Environmental Sampling and Analysis.” *Journal of Alloys and Compounds* 271–273: 11–18.

Donohue, David, Stein Deron, and Erwin Kuhn. 1994. “Environmental Monitoring and Safeguards: Reinforcing Analytical Capabilities.” *IAEA Bulletin* 36(3): 20–23.

Einhorn, Robert J. 2006. “Identifying Nuclear Aspirants and Their Pathways to the Bomb.” *The Nonproliferation Review* 13(3): 491–99.

Farber, Henry S., and Joanne Gowa. 1997. “Common Interests or Common Polities? Reinterpreting the Democratic Peace.” *The Journal of Politics* 59(2): 393–417.

Ferguson, Matthew, and Claude Norman. 2010. *All-Source Information Acquisition and Analysis in the IAEA Department of Safeguards*. Vienna, VA: International Atomic Energy Agency.

Firmage, Edwin Brown. 1969. “The Treaty on the Non-Proliferation of Nuclear Weapons.” *American Journal of International Law* 63: 711–46.

Fitzpatrick, Mark. 2007. *Nuclear Black Markets: Pakistan, A.Q. Khan and the Rise of Proliferation Networks*. London, UK: International Institute for Strategic Studies.

Fuhrmann, Matthew. 2008. “Exporting Mass Destruction? The Determinants of Dual-Use Trade.” *Journal of Peace Research* 45(5): 633–52.

———. 2009. “Spreading Temptation: Proliferation and Peaceful Nuclear Cooperation Agreements.” *International Security* 34(1): 7–41.

———. 2012. *Atomic Assistance: How “Atoms for Peace” Programs Cause Nuclear Insecurity*. Ithaca, NY: Cornell University Press.

Fuhrmann, Matthew, and Jeffrey D. Berejikian. 2012. “Disaggregating Noncompliance Abstention Versus Predation in the Nuclear Nonproliferation Treaty.” *Journal of Conflict Resolution* 56(3): 355–81.

Fuhrmann, Matthew, and Michael C. Horowitz. 2015. “When Leaders Matter: Rebel Experience and Nuclear Proliferation.” *The Journal of Politics* 77(1): 72–87.

Fuhrmann, Matthew, and Sarah E. Kreps. 2010. “Targeting Nuclear Programs in War and Peace: A Quantitative Empirical Analysis, 1941-2000.” *Journal of Conflict Resolution* 54(6): 831–59.

Fuhrmann, Matthew, and Yonatan Lupu. 2016. “Do Arms Control Treaties Work? Assessing the Effectiveness of the Nuclear Nonproliferation Treaty.” *International Studies Quarterly* 60(3): 530–539.

Fuhrmann, Matthew, and Benjamin Tkach. 2015. “Almost Nuclear: Introducing the Nuclear Latency Dataset.” *Conflict Management and Peace Science* 32(4): 443–61.

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

Gerzhoy, Gene. 2015. “Alliance Coercion and Nuclear Restraint: How the United States Thwarted West Germany’s Nuclear Ambitions.” *International Security* 39(4): 91–129.

Goldschmidt, Pierre. 2001. “Strengthened Safeguards: Meeting Present and Future Challenges.” *IAEA Bulletin* 43(4): 6–11.

Gowa, Joanne. 1999. *Ballots and Bullets: The Elusive Democratic Peace*. Princeton, NJ: Princeton University Press.

Gruemm, H. 1983. “Safeguards Verification-Its Credibility and the Diversion Hypothesis.” *IAEA Bulletin* 25(4): 27–29.

Hastie, Trevor, and Robert Tibshirani. 1993. “Varying-Coefficient Models.” *Journal of the Royal Statistical Society. Series B (Methodological)* 55(4): 757–96.

Heising, Carolyn D. 1982. “Quantification of Nuclear Diversion Risks Promises and Problems.” *Energy Policy* 10(2): 101–8.

Hirsch, Theodore. 2004. "The IAEA Additional Protocol: What It Is and Why It Matters." *The Nonproliferation Review* 11(3): 140–66.

Hoodbhoy, Pervez. 2015. "Pakistan, the Saudis' Indispensable Nuclear Partner." *The New York Times,* 22 April.

Horowitz, Michael C., 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.

Hymans, Jacques E. C. 2006. *The Psychology of Nuclear Proliferation: Identity, Emotions, and Foreign Policy*. Cambridge, UK: Cambridge University Press.

International Atomic Energy Agency. 2005a. *Implementation of the NPT Safeguards Agreement in the Islamic Republic of Iran*. Board of Governors Resolution.

———. 2005b. *Strengthening the Effectiveness and Improving the Efficiency of the Safeguards System Including Implementation of Additional Protocols (GC(49)/1)*. Report to the IAEA General Conference.

Jennekens, Jon. 1990. "IAEA Safeguards: A Look at 1970-1990 and Future Prospects." *IAEA Bulletin* 32(1): 5–10.

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

Kaplow, Jeffrey M., and Rebecca Davis Gibbons. 2015. *The Days After a Deal with Iran: Implications for the Nuclear Nonproliferation Regime*. Washington, DC: RAND Corporation.

Kerr, Paul. 2005a. "IAEA Board Closes Safeguards Loophole." *Arms Control Today*.

———. 2005b. "IAEA Board Seeks Strengthened Safeguards." *Arms Control Today*.

Khan, Feroz Hassan. 2012. *Eating Grass: The Making of the Pakistani Bomb*. Palo Alto, CA: Stanford University Press.

Kim, Lance K, Guido Renda, and Giacomo G M Cojazzi. 2015. "Methodological Aspects on the IAEA State Level Concept and Related Acquisition Path Analysis." *Paper prepared for 37th ESARDA Symposium, Manchester, UK*.

Knopf, Jeffrey W. 2018. "After Diffusion: Challenges to Enforcing Nonproliferation and Disarmament Norms." *Contemporary Security Policy* 39(3): 367–98.

Kroenig, Matthew. 2009a. "Exporting the Bomb: Why States Provide Sensitive Nuclear Assistance." *American Political Science Review* 103(1): 113–33.

———. 2009b. “Importing the Bomb: Sensitive Nuclear Assistance and Nuclear Proliferation.” *Journal of Conflict Resolution* 53(2): 161–80.

———. 2010. *Exporting the Bomb: Technology Transfer and the Spread of Nuclear Weapons*. Ithaca, NY: Cornell University Press.

Levite, Ariel E. 2003. “Never Say Never Again: Nuclear Reversal Revisited.” *International Security* 27(3): 59–88.

Mearsheimer, John J. 1994. “The False Promise of International Institutions.” *International Security* 19(3): 5–49.

Mehta, Rupal N., and Rachel Elizabeth Whitlark. 2017a. “The Benefits and Burdens of Nuclear Latency.” *International Studies Quarterly* 61(3): 517–28.

———. 2017b. “The Determinants of Nuclear Latency.” *Working paper*.

Miller, Nicholas L. 2014a. “Nuclear Dominoes: A Self-Defeating Prophecy?” *Security Studies* 23(1): 33–73.

———. 2014b. “The Secret Success of Nonproliferation Sanctions.” *International Organization* 68(04): 913–944.

———. 2017. “Why Nuclear Energy Programs Rarely Lead to Proliferation.” *International Security* 42(2): 40–77.

Montgomery, Alexander H. 2005. “Ringing in Proliferation: How to Dismantle an Atomic Bomb Network.” *International Security* 30(2): 153–87.

———. 2013. “Stop Helping Me: When Nuclear Assistance Impedes Nuclear Programs.” In *The Nuclear Renaissance and International Security*, eds. Adam Stulberg and Matthew Fuhrmann. Palo Alto, CA: Stanford University Press, 177–202.

Narang, Vipin. 2017. “Strategies of Nuclear Proliferation: How States Pursue the Bomb.” *International Security* 41(3): 110–50.

National Intelligence Council. 2007. *Iran: Nuclear Intentions and Capabilities*.

Nieman, Mark David. 2016. “Moments in Time: Temporal Patterns in the Effect of Democracy and Trade on Conflict.” *Conflict Management and Peace Science* 33(3): 273–93.

Norris, Robbert S., and Hans M. Kristensen. 2010. “Global Nuclear Weapons Inventories, 1945–2010.” *Bulletin of the Atomic Scientists* 66(4): 77–83.

Nuclear Threat Initiative. 2017. “Iran Facilities: Nuclear.”

Office of the Director of National Intelligence. 2008. “Background Briefing with Senior U.S. Officials on Syria’s Covert Nuclear Reactor and North Korea’s Involvement.”

Park, Jong Hee. 2010. “Structural Change in U.S. Presidents’ Use of Force.” *American Journal of Political Science* 54(3): 766–782.

Pellaud, Bruno. 2000. “The Strengthened Safeguards System: Objectives, Challenges and Expectations.” In *Tightening the Reins*, eds. Erwin Häckel and Gotthard Stein. Berlin, Germany: Springer, 89–98.

Perkovich, George. 2006. “The End of the Nonproliferation Regime?” *Current History* 105(694): 355–62.

———. 2008. “Nuclear Developments in the GCC: Risks and Trends.” In *Gulf Yearbook 2007-2008*, Dubai, UAE: Gulf Research Center.

Reiss, Mitchell. 1995. *Bridled Ambition: Why Countries Constrain Their Nuclear Capabilities*. Washington, DC: Woodrow Wilson Center Press.

Reiter, Dan. 2014. “Security Commitments and Nuclear Proliferation.” *Foreign Policy Analysis* 10(1): 61–80.

Reynolds, Celia L., and Wilfred T. Wan. 2012. “Empirical Trends in Sanctions and Positive Inducements in Nonproliferation.” In *Sanctions, Statecraft, and Nuclear Proliferation*, ed. Etel Solingen. Cambridge, UK: Cambridge University Press, 56–122.

Rhodes, Richard. 1986. *The Making of the Atomic Bomb*. New York, NY: Simon & Schuster.

Rublee, Maria Rost. 2009. *Nonproliferation Norms: Why States Choose Nuclear Restraint*. Athens, GA: University of Georgia Press.

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

———. 2010. “Nuclear Latency and Nuclear Proliferation.” In *Forecasting Nuclear Proliferation in the 21st Century*, eds. William C. Potter and Gaukar Mukhatzhanova. Palo Alto, CA: Stanford University Press, 80–101.

Samore, Gary. 2005. *Iran’s Strategic Weapons Programmes: A Net Assessment*. London, UK: International Institute for Strategic Studies.

Sauer, Tom. 2006. “The Nuclear Nonproliferation Regime in Crisis.” *Peace Review* 18(3): 333–40.

Schanfein, Mark. 2008. "International Atomic Energy Unattended Monitoring Systems." In *Nuclear Safeguards, Security, and Nonproliferation*, ed. James E. Doyle. Burlington, MA: Butterworth-Heinemann, 113–133.

Silvennoinen, P., and J. Vira. 1981. "An Approach to Quantitative Assessment of Relative Proliferation Risks from Nuclear Fuel Cycles." *Journal of the Operational Research Society* 32(6): 457–66.

———. 1986. "Quantifying Relative Proliferation Risks from Nuclear Fuel Cycles." *Progress in Nuclear Energy* 17(3): 231–43.

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

Smith, Bradley C., and William Spaniel. 2018. "Introducing -CLEAR: A Latent Variable Approach to Measuring Nuclear Proficiency." *Conflict Management and Peace Science*: 0738894217741619.

Sokolski, Henry D. 2008. "Assessing the IAEA's Ability To Verify the NPT." In *Falling Behind: International Scrutiny of the Peaceful Atom*, ed. Henry D. Sokolski. Carlisle, PA: Strategic Studies Institute.

Solingen, Etel. 2007. *Nuclear Logics: Contrasting Paths in East Asia and the Middle East*. Princeton, NJ: Princeton University Press.

Spaniel, William. 2019. *Bargaining over the Bomb: The Successes and Failures of Nuclear Negotiations*. Cambridge, UK: Cambridge University Press.

Spector, Leonard S. 2016. "A Proliferation Plateau May Offer Unique Opportunities." *Arms Control Today* 46(3).

Spirling, Arthur. 2007. "Bayesian Approaches for Limited Dependent Variable Change Point Problems." *Political Analysis* 15(4): 387–405.

Tannenwald, Nina. 2007. 87 *The Nuclear Taboo: The United States and the Non-Use of Nuclear Weapons since 1945*. Cambridge, UK: Cambridge University Press.

Tape, James, and Joseph Pilat. 2008. "Nuclear Safeguards and the Security of Nuclear Materials." In *Nuclear Safeguards, Security, and Nonproliferation*, ed. James E. Doyle. Burlington, MA: Butterworth-Heinemann, 17–30.

The White House. 2015. "Parameters for a Joint Comprehensive Plan of Action Regarding the Islamic Republic of Iran's Nuclear Program."

Ullom, Joel. 1994. "Enriched Uranium versus Plutonium: Proliferant Preferences in the Choice of Fissile Material." *The Nonproliferation Review* 2(1): 1–15.

Vaez, Ali. 2015. “Missing the Point on Iran’s Nuclear Breakout Time.” *Al Jazeera America*, 2 March.

Volpe, Tristan A. 2017. “Atomic Leverage: Compellence with Nuclear Latency.” *Security Studies* 26(3): 517–44.

Way, Christopher, and Jessica L. P. Weeks. 2014. “Making It Personal: Regime Type and Nuclear Proliferation.” *American Journal of Political Science* 58(3): 705–19.

Wellerstein, Alex. 2013. “How Many People Worked on the Manhattan Project?” *Restricted Data: The Nuclear Secrecy Blog*. http://blog.nuclearsecrecy.com/2013/11/01/many-people-worked-manhattan-project/.

Wesley, Michael. 2005. “It’s Time to Scrap the NPT.” *Australian Journal of International Affairs* 59(3): 283–99.

Western, Bruce, and Meredith Kleykamp. 2004. “A Bayesian Change Point Model for Historical Time Series Analysis.” *Political Analysis* 12(4): 354–74.

Williams, Joshua, and Jon B. Wolfstahl. 2005. *The NPT at 35: A Crisis of Compliance or a Crisis of Confidence?* New York, NY: Carnegie Endowment for International Peace.

Wohlstetter, Albert. 1976. “Spreading the Bomb without Quite Breaking the Rules.” *Foreign Policy* 25(Winter): 88–96, 145–179.