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The Case for Institutionalizing Nuclear Munitions: A Probabilistic Game Theory Analysis

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A Thesis in the Field of International Relations

For the Degree of Liberal Arts in Extension Studies

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Abstract

The spread of nuclear weapons is a hotly debated topic, with two dominating schools of thought. One school espouses the belief that horizontal nuclear proliferation is inevitable and that increased proliferation engenders nuclear deterrence. The other school of thought argues that nuclear weapons are an ever-present risk, and that we should strive for near-zero reduction of nuclear armaments.

This thesis hypothesizes that there is a third option in which nuclear deterrence can be held by a collective versus a single nation-state, which can then engender trust and increase security. The methods used to prove this hypothesis are based on evaluating multiple scenarios of both acquisition and use, and evaluating how institutionalized nuclear weapons would work under each of these scenarios.

In this thesis, I reconsider the assumptions of proliferation, and use probabilistic analysis and a game theory payoff model to understand how an institutional model may mitigate risk.

Acknowledgements

This thesis is dedicated to my mother, who is battling cancer at this very moment. She continues to inspire me every single day. It is comforting to know that the very technology that powers nuclear weapons is also helping cure her, and millions like her.

I am also thankful to my wife and my father, who have been very understanding and supportive throughout this process. And I hope this thesis helps contribute in some small way to help build a safer world for my two year old son, who is a source of my hope and strength in these uncertain times.

This work would not have been possible without the insights of Professor Muhammet Bas, who provided me with key pointers and directions that were instrumental to my analysis. His feedback forced me to reassess my fundamental assumptions and strengthen my analysis. Thank you for your continued support and latitude.

Finally, I would also like to offer my gratitude to Professor Doug Bond and Stephen Blinn, for their understanding and accommodation of my extension request.

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Preface

When writing this thesis, I made many international trips: I visited my family in India, flying through the United Arab Emirates on multiple occasions; I traveled to Germany, Denmark, Switzerland, and Canada for my job while living in the United States. At security checkpoints in four different countries, my textbooks and research on nuclear weapons seemed to cause considerable concern.

At Boston Logan International Airport, the presence of multiple textbooks may have triggered the x-ray, but the titles of those books certainly caught the eye of the senior security officers, who subjected me to an hour-long interrogation. They confiscated my notebook containing numerous probability calculations on nuclear proliferation. To date, I have not received them back. In Dubai, the textbooks caused a similar reaction, thankfully tempered when I produced my Harvard student ID. Airport security personnel at Toronto (Canada) Pearson International Airport were less generous, and my textbook *Nuclear Terrorism: The Ultimate Preventable Catastrophe* by Graham Allison was confiscated, along with my notes inside. However, I was given a receipt acknowledging the confiscation (unlike the TSA). Flying back from India on the eve of Indian Independence Day, military security at Chennai International Airport decided that the books (and I) merited multiple screenings, and I had the opportunity to meet at least four separate dogs. Prefacing the search by stating that I was with a cancer patient who was undergoing chemo and radiation therapy probably did not help the situation.

Surprisingly, the Western European countries I visited did not judge my choices of academic literature, and I flew uninterrupted through Zurich, Munich, Frankfurt,

Berlin, and Copenhagen, and my books received no additional scrutiny (beyond what my presence warranted). At the North American airports of New York La Guardia, Miami, and Atlanta Hartsfield Jackson, no one deemed it necessary to screen or confiscate my textbooks and research. In contrast, both Boston Logan International Airport and Toronto Pearson International Airport took note of my Harvard student ID number for reference. Suffice to say I have stopped carrying my textbooks with me when I fly.

While the increased scrutiny was certainly upsetting at the time of those incidents, it was also a reminder of the public perception of nuclear weapons as threats. Yes, these were security personnel, but their reaction to my textbooks and my topic of research suggested some degree of fear when it came to the subject of nuclear terrorism. The alarmist reactions, assiduous inquiries, and increased scrutiny oddly served to reassure me that this is not a topic to be taken lightly. Their acceptance of my pursuit of such subjects was also reassuring, as is the academic freedom to better study and understand that which terrifies us.

We live in tumultuous times. With the rise of authoritarian regimes and fascism around the world, the academic theory of nuclear war seems all too real. Political change in the United States, along with similar movements in Europe and Asia, makes it all the more necessary to address the specter of war before it takes shape into a global nuclear catastrophe.

During the course of writing this thesis, it was often hard to separate the quantitative analysis from the impact of those scenarios. While the probability of full escalation maybe miniscule, it is still a tangible number, and one that could result in the deaths of millions, if not more. It behooves us to consider that as we explore ways to make this world a safer place.

Chapter I

Introduction: Schools of Thought in Nuclear Security

The study of nuclear proliferation is rife with research that espouses both the value of deterrence from increased horizontal proliferation as well as the value of near-zero reduction of nuclear armaments. However, both schools agree that the use of nuclear weapons in any form is not an ideal outcome. It is with this lens that I approached this thesis research into both approaches.

The overarching goal of my thesis is to produce a balanced review of theories proposed by Kenneth Waltz (2010), who argues for the increased spread of nuclear weapons as a safer option, and Scott Sagan (1996), who argues for a reduction in the number of states possessing nuclear weapons. I also seek to develop a clearer picture and assess the validity of what a hybrid alternative to current nuclear weapon proliferation debates might look like.

Most political theorists espouse one of these two dominant theories concerning nuclear proliferation, disarmament, and security. This appears to be so despite the rapidly changing landscape of nuclear capabilities and state actors—factors that have become increasingly relevant as non-state actors such as the Islamic State in Iraq and Syria (ISIS) gain a stronger foothold while dictators feel more emboldened to make nuclear threats.

Applying both schools of thought in the context of an increasingly interconnected global political economy is crucial to better understanding the infrastructure needed to strike a balance between security and disarmament. What I also hope to achieve is

bringing to light new questions designed to encourage greater debate regarding nuclear proliferation and containment, how to incentivize states to cooperate, and use this information to better predict (and prepare for) future nuclear weapons-related issues.

There is growing evidence that threats to use radiological and/or chemical weapons has been employed by various terrorist groups around the world, although such threats garner little media and/or political attention. What current theorists and practitioners fail to consider is the fluidity of "rationality" versus "irrationality." It is widely assumed that irrational states behave irrationally, and one must attempt to consider how, why, and under what circumstances such "irrational" actors behave rationally, as traditional state-actors might. Without such considerations, it becomes highly difficult to describe realistic nuclear deterrents that are relevant to the current political economic climate. I will define different layers within "rationality" and "non-rational" actors as well as what kinds of actions may be considered "rational" and/or "irrational" within the framework of international relations. This is an important consideration, as most traditional international relations theorists assume that non-rational, non-state actors behave alone and "irrationally," when in fact several are incredibly organized, strongly supported financially, and heavily networked.

The modern political economic climate makes it all the more important to treat state and non-state actors with equal credibility in terms of the legitimacy and seriousness of their threats (Abulof, 2013, 2014; Wohlforth, 1999). In many cases, organizations that would be deemed as non-rational states in traditional terms have wider reach in their respective host states than the official governments.

I will define under what conditions a state may be considered a *de facto* rational state despite its apparent terrorist underpinnings. It will likely be defined by the amount

of political, geographical, financial support, and influence it holds. The results will then be compared to the political, geographical, financial support, and influence that a rational state holds (Abulof, 2014). Abulof (2013, pp. 690-693) specifically talks about how "insecure regimes" could use "nuclear diversion" to "address its eroding legitimacy," and that their perceived legitimacy could be extended to organizations they support (e.g., Hezbollah).

Similarly, the ability to acquire nuclear weapons is not necessarily binary but rather fluid based on certain capabilities (Jo & Gartzke, 2007; Fuhrmann & Tkach, 2015, 2016). Gartzke and Jo (2006) identified seven unique traits that could be used to discern where a nation-state falls on the nuclear capability spectrum. Fuhrmann and Tkach (2015) show that of thirty countries that are nuclear-capable (i.e., have latent nuclear ability), only a third have nuclear munitions. Examining this data through a deal-making lens, Bas and Coe (2016, p. 31) hypothesize that this is probably the result of deals between these countries and the U.S. and other states to contain proliferation. In order to have a more nuanced and complete view, I also analyzed Fuhrmann and Tkach's Nuclear Latency dataset (2015), then used a combination of the Gartzke-Jo index and the Fuhrmann-Tkach latency dataset to identify nation-states capable of producing or acquiring nuclear munitions.

I propose taking a probabilistic approach that is not binary in nature for both rationality as well as likelihood of acquisition. This places rationality and the ability to procure nuclear weapons on a spectrum of probability. When examining rationality, I will look at the World Bank's governance indicators to come up with a suitable and comparable proxy. I evaluate the probabilities using two lenses, namely, national ownership of nuclear weapons versus institutional ownership of nuclear weapons. My

ultimate goal in this thesis is to identify scenarios with sets of probabilities that minimize both use and retaliation of nuclear weapons.

In Chapter I, I explore various schools of thought in nuclear security, and how they apply to the goal of minimizing both use and retaliation of nuclear weapons. In Chapter II considers how cooperation maybe a better solution than coercion, and explores existing research on security assurances, credible minimum deterrence, and non-proliferation. I will also examine why there is a need for increased transparency to minimize acquisition and use of nuclear weapons, and the role that multiculturalism may play, specifically in the Middle East and the Mediterranean. While cooperation is always preferred, it is an externality—use of nuclear weapons could happen as a pre-emptive measure or because of regime change and/or other causes internal to a nation state, which is also explored in Chapter II. Finally, since the thesis hinges on institutional ownership of nuclear weapons, I also examine the need for institutional legitimacy and the role that would play.

Chapter III provides a framework for analyzing nuclear security and identifies various scenarios I will evaluate. While my view of acquisition is indigenous development, could nuclear weapons also be acquired through purchase? This question is addressed in this chapter, along with definitions of state versus non-state actors and institutions. Chapter IV outlines my specific approach, and how the various scenarios will be evaluated.

In Chapter V, I perform a quick iterative prisoner's dilemma analysis on the likelihood of states giving up their nuclear munitions. I also consider other approaches in game theory and other factors such as noise, and their impacts on my assumptions.

Chapters VI, VII, and VIII provide an overview of my analytical approach based on the framework in the previous chapters. The chapters explore various configurations for both state and institutional ownership of nuclear munitions under various stability configurations.

In Chapter IX, I examine the security risk(s) in state versus institutional ownership of weapons. I examine whether or not institutions could potentially be safer in terms of protecting "loose nukes" and decreasing the overall risk of proliferation. Chapter X examines approaches for preventing nuclear war, such as deterrence through attribution forensics and avoiding nuclear conflict through diplomacy. I also look at the Treaty on the Non-Proliferation of Nuclear Weapons (colloquially known as Non-Proliferation Treaty, or NPT) and its role in preventing a nuclear catastrophe, as well as the role of strong nuclear allies and security alliances.

Finally, in Chapter XI, I make a recommendation that sums up my research. Based on this analysis, I will provide an overview of how institutional ownership may or may not be better than state ownership of nuclear munitions, and the conditions and criteria needed to make an institutional model work based on this research. Chapter XII concludes the analysis by providing a straw-man institutional charter that strives to illustrate how such an institution might work, derived directly from my observations in earlier chapters.

Chapter II

Cooperation as an Alternative to Coercion

In his publication, "Why Do States Build Nuclear Weapons?," Sagan (1996) proposes three concepts for modeling to explain the rationale of proliferation:

1. Security, to protect the sovereignty and national security from international threats (Waltz, 1979).
2. Domestic politics, manifested by internal machinations and interests (both military and non-military) and the influence of a state's nuclear energy establishments
3. Norms of what is acceptable in the international relations arena, how that shapes a nation's identity, and how nuclear weapons fit in such a worldview.

While these models each present valid reasons why countries might pursue a nuclear munitions capability, Kapstein (1995) takes a similar position, i.e., that there is no consensus around a "well-developed domestic political theory of nuclear weapons proliferation" (pp. 751-754). Even though there are many schools of thought, there is no consensus on how these three models might come together to explain nuclear proliferation. I posit that this may be because of the limited amount of data regarding nations with nuclear munitions capability, and the difficulty of testing hypotheses for any model in this space.

This is a key factor as I evaluate the feasibility of security alliances and nuclear allies. Glenn Snyder (1984) talks about the security dilemma as a "choice between

support or nonsupport of allies, and tension between fears of entrapment and abandonment" (p. 466) and how it represents "choice . . . between firmness and conciliation toward the opponent" (p. 468). In Chapter V, I evaluate several game theory strategies for their viability. While "tit for tat" emerged as the best strategy, it is worth noting that "cooperation" also emerged equally on top. If I prioritized the data based on risk outcomes (i.e., use of nuclear munitions), then "cooperation" from both parties emerges at the top (i.e., 0% use).

Spaniel (2011) theorizes that being unaware of each other's motives, players often choose defection, as it represents the most stable outcome. However, defection has a very low payout as an outcome (either individual or mutual), and as strategies evolve with improved information, cooperation emerges as one of the top choices. As such, I can posit that improved information on a nation's intentions would, in fact, allay Snyder's (1984) "fears of entrapment and abandonment" (p. 466) and enable an informed choice between "firmness and conciliation" (p. 468).

Security Assurances, Credible Minimum Deterrence, Security Dilemma, and Non-Proliferation

Basrur (2009) talks about how the presence of nuclear munitions capability can introduce "new dimensions" of insecurity that are not easy to address. He calls nuclear weapons both "usable" and "unusable" given the complex web of morality, ethics, practicality, and international politics that govern and discourage the use of nuclear munitions. However, possession of minimum deterrence through nuclear weapons may be able to reduce such insecurities while reducing the risk that comes from vertical proliferation. He explains that a country sees its ownership of nuclear munitions as

defensive, while other nations see it as offensive. He discusses India's strategy of "credible minimum deterrence" and suggests that large stockpiles of nuclear munitions are not necessary to provide a reasonable modicum of defensive security in a nuclear munitions-capable world.

It would be helpful to understand how credible minimum defensive deterrence could be provided as a security assurance to nations that do not possess (or are not capable of possessing) nuclear munitions. It is exactly this that George Bunn and Roland Timerbaev address in their 1993 paper. The authors note that prior to becoming a nuclear-weapon state (NWS), a non-aligned India sent delegations to non-nuclear-weapon states (NNWS) in 1968, seeking security assurances in the eventuality of a Chinese nuclear threat. The delegations were ignored. Therefore, India refused to sign the NPT, and subsequently became a NWS. In contrast, the near-nuclear-capable states, such as Germany, Japan, and Italy, were given security commitments and assurances from the United States, which had the effect of forestalling those countries from becoming NWSs. Bunn and Timerbaev (1993) note that the Soviet Union provided similar assurances to its allies, but Blacker (1993) notes that those assurances became useless when the former Soviet states separated from the Soviet Union.

In this context, it is worthwhile to examine Robert Jervis' seminal work, *Cooperation Under the Security Dilemma* (1978). He talks about how the security dilemma arises when "many of the means by which a state tries to increase its security decreases the security of others" (p. 169). Glaser (1997) notes how the "magnitude and nature of the security dilemma depend on two variables: the offense-defense balance and offense-defense differentiation" (p. 171). In essence, either an increase in conventional warfare capabilities or working toward a functional nuclear munitions capability could be

seen as an increase in a nation's own security at the expense of the security of others. Seen through Jervis' lens, India's pre-existing superior conventional military would understandably be seen as a security threat by the smaller Pakistan, particularly given the creation of Bangladesh following India's liberation of East Pakistan in 1971. Similarly, American (Jalal, 1987; Fair, 2008) and Chinese (Afridi & Bajoria, 2010) support of Pakistan, aimed at strengthening Pakistan's security, would have been seen by India as a threat to its own national security. As such, both nations sought to tip the balance of power in their favor through differentiation, which the acquisition of nuclear weapons provided.

While the need for differentiation may be explained through Jervis' model, Glaser (1997) provides two additional variables that could help explain why nations may choose nuclear weapons as a means of differentiation. Glaser (1997) argues that other motives besides security (e.g., greed), combined with granular information about a nation's motives, could help explain the scope and magnitude of the security dilemma (p. 174). Seen through this lens, the acquisition of nuclear munitions capabilities makes sense. Both India and Pakistan signaled motives beyond national security (e.g., Jammu and Kashmir; emergence of jingoistic right-wing nationalism in both countries, etc), which exacerbated the magnitude of differentiation beyond conventional weapons. For an institutional model to work, signaling institutional motives maybe helpful in preventing such proliferation.

When examining the history of non-proliferation, specifically the NPT, one challenge uniquely stands out: the difficulty of getting nations to agree on "negative assurances" (i.e., a promise to not attack a signatory with nuclear weapons). Indeed, United Nations Security Council Resolution 255 (1968) does not contain any negative

assurances. While all the NWSs have subsequently made unilateral commitments of "no first use," these are not legally binding, and in many instances they are also worded such that first use may be justified under certain circumstances (Bunn & Timerbaev, 1993). This observation is important for two reasons: (1) nations use nuclear weapons as a threat, and (2) negative assurances significantly reduce their purpose to this end.

An equally damning factor was the imposition of a treaty duration, particularly by Germany and Italy, in preparation for the eventuality that it would not be in the United States' best interest to honor its commitments with NATO forever (Bunn & Timerbaev, 1993). This speaks to the near-term perception of security alliances, particularly when it comes to nuclear weapons. But Jervis (1978) notes that cooperation is much more likely "when the costs of being exploited and the gains of exploiting others are low, when the gains from mutual cooperation and the costs of mutual non-cooperation are high, and when each side expects the other to cooperate" (p. 167) and that the security dilemma is mitigated when the nations on the defensive have a clear advantage over nations on the offense, and when there is a clear distinction between defensive and offensive postures.

Seen through these lenses, a pattern begins to emerge on what nations consider credible deterrence. While defense maybe a stated objective, the defense is only useful if backed by a credible threat, and the reluctance to provide negative assurances reinforces this point. Such a threat also needs to be superior and clearly differentiated, as noted by Jervis (1978) and Glaser (1997), both to mitigate the security dilemma as well as to ensure that nuclear weapons are seen as a credible deterrent. India's decision to acquire nuclear weapons when it was unable to acquire reasonable security guarantees further reiterates this point. Security assurances are only meaningful when backed by meaningful alliances; thus, when the Soviet Union collapsed, the security assurances also collapsed.

The insistence by United States' allies to tie their non-acquisition to the lifetime of NATO also corroborates this assumption.

For non-proliferation to work in an institutional model, any institution should be able to provide legally binding assurances, both positive and negative. While such assurances maybe conditional (e.g., no first use), it may not be ideal to make them durational (e.g., expires in a decade), as it removes any incentive to truly abandon pursuit of nuclear munitions capability.

Another factor to consider is "nuclear posturing," where some nations adopt policies that allow for the use of nuclear weapons if necessary, even as a first use. In 1993, Russia reversed its "No First Use" pledge, which Brezhnev had made in 1982, doing so by citing the U.S. and NATO's growing superiority in conventional warfare and weapons (Lockwood, 1993). Others, notably France, North Korea, Pakistan, United Kingdom, United States, and Israel, as well as NATO, have not ruled out the use of nuclear weapons even in conventional warfare (Mendelsohn, 1999). Indeed, the 19 nations in NATO continue to maintain their policy of "flexible response," where nuclear weapons maybe used in conventional warfare is necessary. Narang (2010) also cites Pakistan as an example of a country that "shifted from catalytic nuclear posture to an asymmetric escalation posture" (p. 38). So far, only China and India have policies of No First Use. Such posturing may not be possible in an institutional model, especially if the objective of an institution is to promote nuclear stability. Indeed, in the case of institutional ownership, the advantage of using the nuclear weapons as a threat in conventional warfare would, in all likelihood, vanish. But it is worth noting that while such posturing is currently effective for Pakistan, North Korea, and Israel, it is somewhat unnecessary for the U.S., Russia, and NATO, which have massive conventional

firepower. Even in the absence of nuclear weapons as deterrence against conventional warfare, however, an institution could refuse to make assurances, either positive or negative, and take steps to formalize its escalation procedures. Furthermore, while such deterrence is only possible for those nations that are nuclear capable, an institutional model is able to provide its aegis of deterrence to those nations that are unable to develop such capabilities on their own.

Need for Increased Transparency and the Role of Multiculturalism

Would a multicultural, cooperative structure work in favor of proliferation or against it? Bruno Tertrais (2005) argues that non-proliferation does work for the European Union, given its inherently multilateral, cooperative structure. Emmanuelle Blanc (2014) talks about how the European Security Strategy uses a gradated escalation of action as a means to minimize use of force and threat, and how non-proliferation works well in this structure. He contrasts this with Israel, which does not hesitate to use force and tends to respond aggressively to threats to forestall further attacks. Blanc argues that since this is an artifact of Israel's security as a nation state, the EU, with the United Nations and the United States, sought to address the root cause of proliferation – Iran (pp. 11-13). He also notes that while Israel approves of the EU's actions, "the real success of these sanctions is not merely their enactment (as it may be for the EU) but rather their actual effectiveness" (p. 22).

However, we have seen that for non-proliferation to be effective, there needs to be credible security assurances. In the EU Barcelona Process agreement as well as subsequent agreements with countries in the Mediterranean and the Middle East, the EU has been "conciliatory for Israel than for the other Mediterranean countries" (Blanc,

2014, p. 23). While Jo and Gartzke (2007) consider Israel to be a *de facto* nuclear state, Israel's nuclear status continues to remain undeclared. Israel may be less than transparent regarding its nuclear capability, but the general consensus is that its nuclear capability provides meaningful deterrence while freeing Israel from the potential negative consequences of admitting to ownership of nuclear munitions (with the accompanying sanctions). This common knowledge may not directly contradict the need for increased transparency required for a more stable equilibrium, but it does corroborate double standards on part of both the EU and the U.S. This is an important factor that I will consider when I explore institutional ownership. Double standards, such as those of the EU in the case of Israel, would diminish predictability and trust, and therefore affect institutional credibility.

The other aspect to consider within the context of EU is that the United States, through NATO, provides credible deterrence, which has mitigated the need for other Western European states to build a nuclear capability. In the absence of such, European states could potentially consider proliferation for deterrence. For instance, during the Cold War (1947-1991), Germany attempted to initiate a French-German nuclear alliance, which failed (von Hammerstein, et al., 2016). Most notably, Chancellor Konrad Adenauer and Defense Minister Franz Josef Strauss sought joint nuclear cooperation with France, but French President Charles de Gaulle stopped all attempts after his election in 1958 (von Hammerstein, et al., 2016). Likewise, in recently released information dating back to 1985, French President François Mitterrand confided in then-Chancellor Helmut Kohl of France's unwillingness to "provide Germany with nuclear protection," because using France's nuclear munitions for deterrence beyond French borders would likely expose France to a more "lethal threat" (von Hammerstein, et al., 2016). In the absence of

security assurances by NATO, it is quite possible that Europe could see its share of vertical and horizontal proliferation. I will discuss this in greater detail in Chapter XI, in the context of how the current political climate in the United States may impact European views of nuclear security.

Pre-emptive Strikes, Regime Change, and Other Stratagems

So far in this analysis, I have only looked at nuclear weapons as a defensive mechanism or a potential tool for retaliation. But what about the use of nuclear weapons as a credible pre-emptive force? Bothe (2003) argues that states would need to be overwhelmed by threats to the point of "necessity and immediacy" (pp. 227, 230) to justify the "doctrine of pre-emptive" action (p. 227) While this is obviously "customary [in] international law" (p. 228), it does not stop nation states from using "anticipatory self defense" as a unilateral excuse for attacking other nation states (p. 228). However, Sofaer (2003) argues that restricting pre-emption places nations that are threatened under duress, and a more flexible approach may be needed. Citing the role of Al Qaeda in the September 11, 2001, attacks in the U.S., Sofaer argues that the "narrow standards" of pre-emption may in some instances provide *casus belli* for increased escalation and war, which could have been prevented in the first place through pre-emptive strikes (p. 209).

Dunn (2007) highlights the problem with the threat of pre-emptive action as a means of coercion vis-à-vis pre-emptive action in and of itself:

> Indeed, the entire Bush policy toward Iran, of simultaneously wishing to coerce, undermine and replace the regime while also seeking to persuade it to abandon its nuclear programme through diplomacy, has proved both strategically inconsistent and consistently counterproductive. In failing to decide whether it prioritizes a change of regime or a change of behaviour it has got neither. (p. 19)

Such criticism is by no means limited to just the Bush administration's view of Iran, but also against the broader U.S. foreign policy, as evidenced in its dealings with North Korea. Bleiker (2003) argues that adopting a monolithic view of North Korea as a "rogue state" prevents most people from adequately understanding the root cause of North Korea's discord and addressing it:

> Particularly significant is the current policy of pre-emptive strikes against rogue states, for it reinforces half a century of American nuclear threats towards North Korea. The problematic role of these threats has been largely obscured, not least because the highly technical discourse of security analysis has managed to present the strategic situation on the peninsula in a manner that attributes responsibility for the crisis solely to North Korea's actions, even if the situation is in reality far more complex and interactive. (p. 719)

In fact, Richard Haass (2005), President of the Council on Foreign Relations, has argued for forced regime change in North Korea, citing concerns about the sale of nuclear fuel or technology, and calling it a third "axis of evil" (pp. 66-78).

It could be argued that continued threats may in fact escalate situations when the fundamental *raison d'être* of belligerence (or threats of belligerence) is not addressed. For instance, Richard Cronin (2005) discusses how threats from China and North Korea may force Japan not only to seek greater military cooperation with the United States but also to strive for "greater defense self-sufficiency" (p. 51). Indeed, even tumultuous situations may not deter a determined party from taking on or continuing an aggressive stance. This was evidenced when Chinese nuclear proliferation did not diminish, even during tense developments in South Asia such as the Kargil War (Ramana, 2011). While China maintained a neutral position during that conflict, such developments only encouraged greater cooperation with Pakistan in sharing nuclear technology: "The nature of the China-Pakistan military/nuclear alliance makes it beneficial for China to extend its

nuclear-proliferation tentacles worldwide through proxies; thereby holding a level of plausible deniability in international forums." (p. 10)

Some portion of this may be attributable to cultural values, as Thomas Christensen (1999) suggests. While China maybe more amenable to multilateralism in economic decisions, there is often a lens of mistrust of Western powers in geopolitical decisions. Ramana (2011) also makes this observation, and posits that China considers multilateral regimes to be discriminatory (p. 8).

As I explored both American foreign policy as well as Chinese actions, the common thread that emerged is that the single-mindedness of pre-emptive threats may foster the very thing it seeks to discourage, or to a lesser extent, not have an impact at all. Indeed, as the dictum of unintended consequences states, outcomes maybe completely independent of actions. Therefore, it behooves us to address the *raison d'être* of discord, rather than use nuclear threats as a singular hammer.

Need for Institutional Legitimacy

Gartzke and Kroenig (2009) discuss how there is an enormous body of literature on the "causes and consequences of nuclear proliferation" (p. 152) but there is very little on how they would impact the "security and diplomacy of the possessors" (p. 152). They acknowledge that Gartzke and Jo's prior research (2007) demonstrates empirically that the presence of absence of nuclear weapons has no bearing on involvement in conflicts; however, the weapons do have a bearing on the bargaining power of these nation states (Gartzke & Kroenig, 2009).

Horowitz (2009) has demonstrated through multiple empirical analyses that duration of nuclear weapons possession has an impact on the probability of conflict,

resolution, reciprocity, and retaliation. He observes that younger and inexperienced NWSs are more likely to engage in conflict as compared to older, more experienced NWSs. Gartzke and Kroenig (2009) also conclude that the possession of nuclear weapons over a longer period of time causes nations to, "become more influential, more successful in the wars they choose to fight, and to have less intense conflicts, when these conflicts occur" (p. 160).

If this were true, then perhaps creating an institution with nuclear weapons and the backing of older, more experienced NWSs might result in an institution that could be considerably more effective in addressing world conflicts. Such an institution would need legitimacy and recognition by other countries. Earlier, I discussed how China views doctrines of multilateralism as discriminatory and influenced by Western powers seeking to control less-developed countries (Ramana, 2011). The double standards of the U.S. and the EU in dealing with *de facto* nuclear powers like Israel or South Africa does not help such a perception (Blanc, 2014). It is therefore quite conceivable that any institution that is perceived as a puppet of the Western powers or as practicing double standards would lack sufficient legitimacy. Indeed, proponents of non-proliferation have often been accused of belonging to an "international regime" with the sole purpose of mutual benefit (Smith, 1987). While it could indeed be called an anomalous "international regime," self-interest and mutual cooperation are in themselves inadequate to explain the emergence and continued existence of such a system. All this begs the question: what would actually be considered institutional legitimacy while promoting non-proliferation?

Ian Hurd, in his book on legitimacy and the power of the United Nations, talks about the behavioral implications of legitimacy (2008). He discusses how both proponents and opponents of the Iraq War sought a Security Council resolution as a

means of lending legitimacy to their points of view, and how institutional legitimacy should be judged by the actions of nations. For instance, U.S. President George W. Bush sought the approval of the United Nations while at the same time disparaging it and questioning its legitimacy (Hurd, 2008). Ruzicka and Wheeler (2010) propose that trust is a fundamental element of interests and promises between nations, and is key to the success of NPT. Seen in this light, the U.S. actions seeking a U.N. resolution for the Iraq War begin to make sense, as they merely reflected the inter-relations and levels of trust between nations.

However, the genesis of such trust comes from the people of these nation, so how do societies perceive the legitimacy of institutions? Lisa Dellmuth and Jonas Tallberg, from Stockholm University, did a study on the social legitimacy of international organizations, particularly the United Nations (2011, 2015). Their findings suggest that democratic procedures have little say in the legitimacy of an institution, while the ability to effect change has a significant role. Perceptions of international organizations were also strongly tied to perceptions of political institutions in general (e.g., domestic political establishment), which would be outside the control of international organizations.

How do we engender institutional legitimacy? Dellmuth and Tallberg's research suggests that robust political institutions coming together to form international organizations would engender trust. Suchman (1995) proposes three types of institutional legitimacies: pragmatic, moral, and cognitive. He posits that in order to garner legitimacy, any institution or organization needs to be pragmatic in its objectives (e.g., prevent nuclear war), moral in its execution (e.g., no double standards and/or not seen as a puppet), and be understandable and relatable by the populace of the participating nation(s) (e.g., how and why would the institution be effective?). Understanding these

characteristics and considering the behavioral implications of any actions should be foremost in any institution's charter. For instance, how would the threat of pre-emption be perceived by various nations? What would a consistent escalation path look like, whether against Israel or Iran? This will help provide a truly multilateral structure, worldview, and broader support. Finally, the backing of powerful (in terms of economic power and political influence) and strong (in terms of nuclear weapons capability) nations is absolutely necessary to lend both experience and effectiveness.

Chapter III

A Proposed Framework for Understanding Nuclear Security

In order to fully understand whether or not a nation will use nuclear weapons, there are three key steps to consider:

- acquisition of nuclear weapons
- use of nuclear weapons
- retaliation for having used nuclear weapons

Jo and Gartzke (2007) proposed seven key indicators that can help gauge a nation's capabilities for building nuclear munitions, based on the Correlates of War and Production Ability Index. I use this score (henceforth called the Jo-Gartzke nuclear munitions capability index) as a proxy for a nation state's ability to produce nuclear munitions. These indicators are:

- Uranium availability: whether or not a country has uranium deposits or access to them
- Metallurgical ability: whether or not a country can process excavated Uranium ores
- Chemical ability: whether or not a country can produce nitric or sulfuric acid
- Explosive materials manufacturing capability: whether or not a country can produce non-organic fertilizer
- Electronic capability: whether or not a country can manufacture radios and televisions

- Nuclear engineering capability: whether or not a country has a nuclear reactor older than 3 years
- Electricity producing capability: the ability to produce over 200MW or electricity equivalent to 50,000 tons of oil

I took scores from 2001 and updated them where possible based on publicly available information. The total count of nuclear-capable nations with a score of 7 remains unchanged at 29. There are 22 nations with a score of 6, which are near-capable of producing nuclear munitions. These numbers include declared nuclear nations (United States, United Kingdom, Soviet Union, France, China), *de facto* nuclear nations (Israel, South Africa, India, and Pakistan), and other nations capable of producing nuclear munitions (e.g., Germany, Japan, Ukraine, Canada, Australia, etc). There are six countries for which we are unable to determine a score (Grenada, St. Kitts & Nevis, San Marino, Palau, Marshall Islands, Nauru).

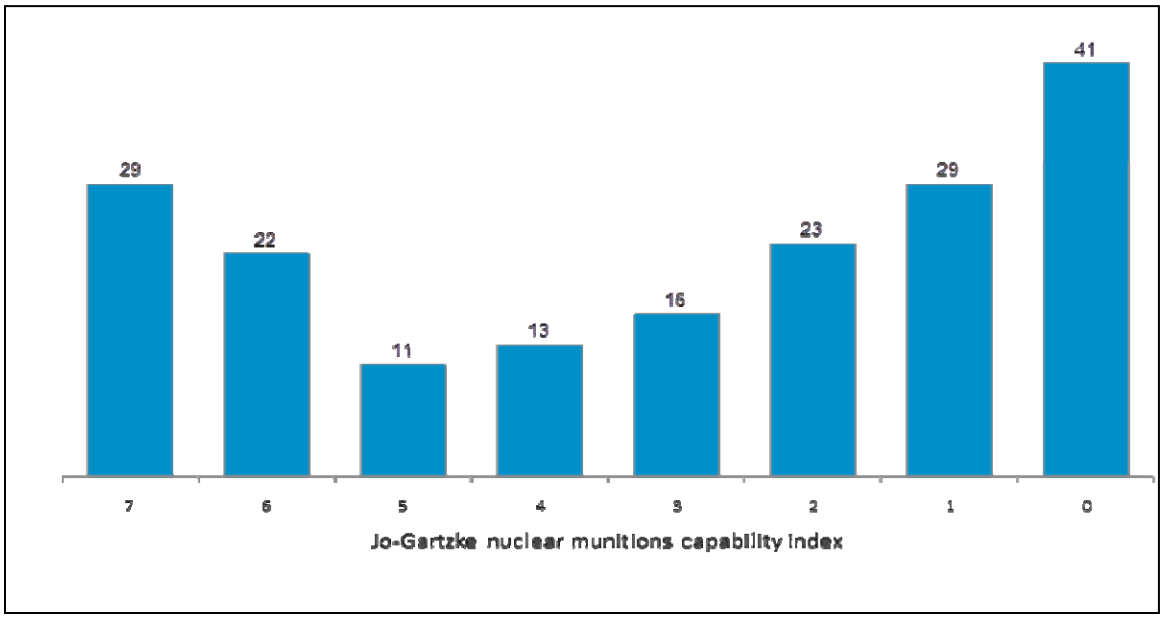

Fig. 1. Number of countries as computed by the Jo-Gartzke Nuclear Munitions Capability Index
Source: Jo & Gartzke, 2007

Table 1. Percentage distribution of countries based on Jo-Gartzke Nuclear Munitions Capability Index

Aggregate JG nuclear score	% of countries	Nuclear munitions capability	Number of countries
7	15%	very high	29
6	11%	High	22
5 and 4	12%	Medium	24
3	8%	Low	16
1 and 2	30%	very low	58
0	21%	Trivial	41
N/A	<3%	data not available	6

Source: Jo & Gartzke, 2007

However, is the Jo-Gartzke measure the only metric by which to gauge acquisition probability? To have a more nuanced and complete view, I also compared Fuhrmann's Nuclear Latency dataset (2016). I filtered based on year (latest being 2012), and looked for countries with either laboratory or pilot measures. The two countries with moderate Jo-Gartzke scores of 5 each were Netherlands and South Africa. However, both countries were gauged active in both the laboratory and the pilot measures. As such, both countries were moved to the top tier in my index. In all my analyses, I provided both the initial Jo-Gartzke distribution as well as the revised distribution based on the Nuclear Latency dataset developed by Fuhrmann, et al. (see Table 2).

Table 2. Revised percentage distribution of countries based on Jo-Gartzke Nuclear Munitions Capability Index and Fuhrmann's Nuclear Latency dataset

% of countries	Nuclear munitions capability	Number of countries
16% (up from 15%)	very high	29 + 2
11%	High	22
11% (down from 12%)	Medium	24 - 2
8%	Low	16
30%	very low	58
21%	Trivial	41
<3%	data not available	6

Source: Jo & Gartzke, 2007; Fuhrmann, et al., 2016

For Tables 1 and 2 (i.e., use and retaliation), Jo and Gartzke (2007) and Graham Allison (2000) propose that nations are likely to use nuclear weapons for one of three main reasons, namely, to demonstrate power, to maximize individual security, or as a diversionary tactic.

Given the world's abhorrence of nuclear weapons, as well as the potential for sanctions and global ostracism, it can be reasonably assumed that a stable and rational nation would not brashly use nuclear weapons for any of the three reasons. However, an irrational nation maybe willing to do so. Therefore, my initial assumption was that I could use stability as a proxy for rationality. See Figure 2 for an illustration.

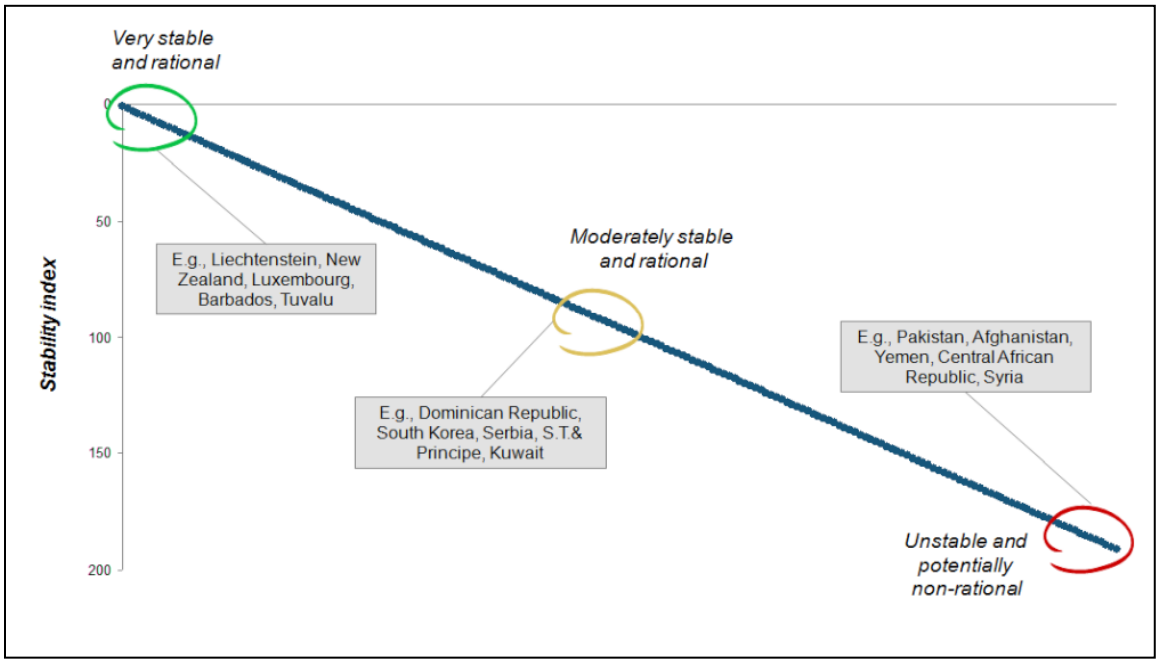

Fig. 2. A rank order view of stability

Source: thesis author

However, stability alone is not a guarantee of rationality. It is entirely possible that a nation could be stable, and yet act irrationally (e.g., an irrational leader or corruption). While I could evaluate nations for historical trends in rational actions, past performance is not always indicative of future actions. As such, I wanted to explore other ways to capture rationality.

I explored indices that could potentially be considered leading indicators of rationality. I came upon the six composite dimensions used by the World Bank as governance indicators (2016):

Voice and Accountability	Regulatory Quality
Political Stability and Absence of Violence	Rule of Law
Government Effectiveness	Control of Corruption

In order to create a more complete view of rationality, I examined each of these. As a result, in addition to the Political Stability, I also looked at Government Effectiveness, Rule of Law, and Control of Corruption as measures that would complement stability to determine rational actions. My rationale is that on top of stability, an effective government has infrastructure in the form of checks and balances as well as legal and/or constitutional frameworks to protect an individual from making an irrational decision (e.g., irrational leader versus rational government and judiciary).

However, it is not sufficient for a country to have an effective government if governance or justice or people can be bought for a price. Therefore, I also looked at how well a country managed corruption within its borders (e.g., irrational leader or government and a rational judiciary willing to stand up to the leader or government, in a stable political and non-violent environment).

The Global Economy website (2016) has made available interactive datasets of the World Bank's governance indicators, and has captured these four dimensions on a 5-point scale (-2.5 to +2.5). I decided to use this data as the basis for my comparison. A summary of the countries in these categories indicated the following (see Figure 3, and Table 3).

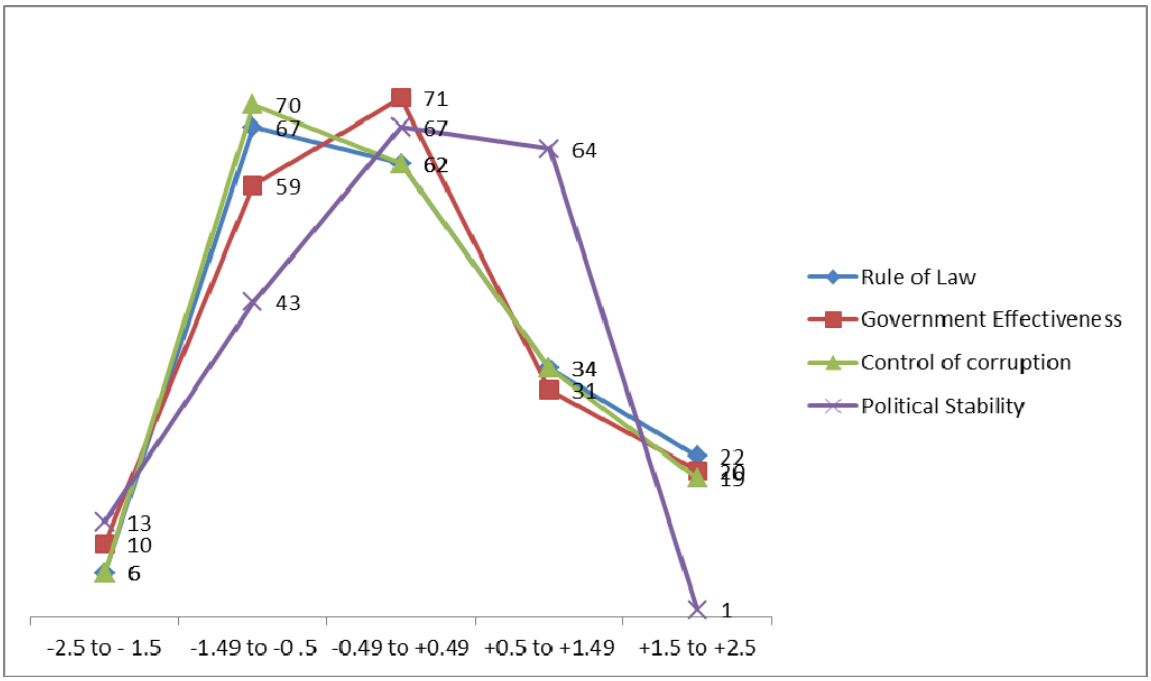

Fig 3. Distribution of countries on a -2.5 to +2.5 scale for Rule of Law, Government Effectiveness, Control of Corruption, and Political Stability

Source: World Bank Governance Indicators, 2016; *Global Economy*, 2016

Table 3. Distribution of countries by number for the selected governance indicators (individual)

	Number of countries with score of				
	-2.5 to -1.5	-1.49 to -0.5	-0.49 to +0.49	+0.5 to +1.49	+1.5 to +2.5
Rule of Law	6	67	62	34	22
Government Effectiveness	10	59	71	31	20
Control of corruption	6	70	62	34	19
Political Stability	13	43	67	64	1

Source: World Bank Governance Indicators, 2016; *Global Economy*, 2016.

Table 4. Distribution of countries by percentage for the selected governance indicators (individual)

	Percentage of countries with score of				
	Very Low -2.5 to -1.5	Low -1.49 to -0.5	Medium -0.49 to +0.49	High +0.5 to +1.49	Very High +1.5 to +2.5
Rule of Law	3.1%	35.1%	32.5%	17.8%	11.5%
Government Effectiveness	5.2%	30.9%	37.2%	16.2%	10.5%
Control of corruption	3.1%	36.6%	32.5%	17.8%	9.9%
Political Stability	6.9%	22.9%	35.6%	34.0%	0.5%

Source: World Bank Governance Indicators, 2016; *Global Economy*, 2016

How would I create a composite index of rationality from these percentages, especially given that there need not be overlap between the categories (e.g., the 5 countries with the poorest rule of law are not the same 5 countries with very little control of corruption)? My initial assumption was that there could be a spectrum of stability bounded by these percentages. That is, in an extremely irrational scenario, perhaps 1% of countries are fully rational. On the far end of the spectrum, the range would be 5–25 countries (i.e., 15 + 5 + 5). But calculating those probabilities would be immensely complex, and would not serve my purpose. So, I propose a composite score that is simply a sum of all four indicators, coded within the same categories (see Table 5 and Table 6).

Table 5. Distribution of countries by number for the selected governance indicators (cumulative)

	Number of countries with score of				
	Very Low -10.00 to -6.00	Low -5.99 to -2.00	Medium -1.99 to +1.99	High +2.00 to +5.99	Very High +6.00 to +10.00
Total score for Rule of Law, Government Effectiveness, Control of Corruption, and Rule of Law	9	54	82	38	18

Source: World Bank Governance Indicators, 2016; *Global Economy*, 2016

Table 6. Distribution of countries by percentage for the selected governance indicators (cumulative)

	% of countries with score of				
	Very Low -10.00 to -6.00	Low -5.99 to -2.00	Medium -1.99 to +1.99	High +2.00 to +5.99	Very High +6.00 to +10.00
Total score for stability, rule of law, and control of corruption	4%	27%	41%	19%	9%

Source: World Bank Governance Indicators, 2016; *Global Economy*, 2016

I will use this distribution as a proxy for rationality, but with an inverse relationship for Use of nuclear munitions (only Use, not Acquisition). I will assume that the nations with Very High (8%, or 15 nations) will behave rationally and have a Very Low probability of Use or Retaliation. The Very Low nations may behave irrationally

and have a Very High probability of Use or Retaliation. While the distribution percentage of these categories will remain unchanged, the number of impacted states will change.

Acquiring Nuclear Munitions Through Purchase

In my approach, I focused primarily on indigenous development of nuclear capability rather than the purchase of nuclear capability. For example, Joshua Sinai (1997; pp. 92-94) talks about Libya's attempts at acquiring nuclear capabilities. While not the physical materials per se, Pakistan's A. Q. Khan also sold blueprints and outlined the capabilities needed to build nuclear weapons to at least four countries over two decades (Albright & Hinderstein, 2005; Jehl, 2004; Khan, 2004).

There are many variables that could affect the current status quo, enabling both state and non-state actors to purchase nuclear weapons. In his paper on "The Likelihood of Nuclear Terrorism" (1985), Brian Jenkins of RAND Corporation talks about how circumstances may change in the acquisition of nuclear weapons. While Jenkins primarily focuses on terrorists (mostly defined as non-state actors in his paper), the scenarios are broadly applicable to other nations as well:

> As nuclear programs expand, nuclear material suitable for use in weapons could become more widely available than it is now. Expanding commercial traffic in explosive nuclear fuel will increase the opportunities for diversion, which in turn could lead to a nuclear gray or black market where terrorists could acquire nuclear material as they now acquire conventional weapons. (p. 9)

What might be the economic circumstances and incentives to trade in nuclear weapons, and is this a realistic scenario? Philippe Jehiel, Benny Moldovanu, and Ennio Stacchetti (1996) address this in excruciating technical detail in their paper, "How (Not) to Sell Nuclear Weapons." They consider the circumstances surrounding Ukraine's "sale"

of its nuclear arsenal to Russia in exchange for security guarantees from Russia, the United States, and NATO member states. Similarly, China also signed treaties agreeing to not sell missile technology to Arab states in exchange for trade deals. What are the economic incentives to sell (or not sell) nuclear munitions?

In their paper, Jehiel, et al., make the point that when a buyer acquires nuclear weapons, they also acquire "incurred externalities (positive or negative)," and the "external effects are assumed to be . . . identity dependent" (p. 816). While the price set by the seller may be endogenous, the effect of externalities—on both the seller and the buyer—is likely to be asymmetric and exogenous in nature (Jehiel, et al., 1996, pp. 815-817). In practical terms, this means that while the acquisition of nuclear weapons may grant some perceived protection, the realistic cost to both buyer and seller would be much more tangible in terms of how other nations react to their actions. The intent to buy or sell could be used as leverage to negotiate better trade deals or even protection, in lieu of not acquiring nuclear weapons. There are also participation constraints where the "buyer's outside options are not exogenous" (Jehiel, et al., 1996, p. 822). While the intent to buy may exist in any scenario, the ability of a buyer to buy is driven entirely by exogenous factors, i.e., a nuclear-capable nation willing to sell. However, Jehiel, et al. (1996) demonstrate that it is in the seller's best interests not to sell if the "sum of externalities created by a sale is larger than all valuations" (p. 825). In the instance of Ukraine, it furthered the cause of non-proliferation when it handed off its nuclear munitions to other nuclear-capable nations. However, if a nation provided its nuclear munitions to a non-nuclear-capable nation, the external effects are likely to be significantly negative, discouraging sale or proliferation.

Therefore, I assume that the probability of acquisition, as I have posited in this thesis, is sufficient. I will also explore in greater detail in Chapter X how proliferation and conflict could be avoided through diplomacy.

States Providing Nuclear Weapons to Non-State Actors

Through the use of two lenses, Keir Lieber and Daryl Press (2016) evaluate the risk of nations providing nuclear munitions to non-state actors: (1) using data on conventional terrorism to determine such attribution; and (2) the technical challenges in performing such attribution (technical challenges are also discussed in additional detail in Chapter IX). Lieber and Press conclude that it would be unlikely for a terrorist group or a state sponsor to remain anonymous after a nuclear attack, for four reasons:

- a strong correlation between number fatalities and attribution
- higher success rates in attribution when it comes to terror attacks on the U.S. or U.S. allies
- a relatively small number of countries likely to support terrorism
- Of those countries, only one has nuclear munitions capability, namely, Pakistan , (p. 84).

Lieber and Press also examine several potential counter-arguments, such as stolen nuclear weapons, or difficulties with attribution, including misattribution. But the authors conclude that sharing nuclear munitions with a non-state actor would require some semblance of trust and control, which would make attribution easier. Furthermore, the very nature of a nuclear attack would likely mobilize world governments on an unprecedented scale, not only to find the perpetrator but also to prevent more attacks. Nations are much more likely to cooperate to establish their innocence quickly in order to

avoid confrontation (Lieber, 2016, p. 100). Finally, the success of attributing large-scale attacks (especially on the U.S. or its allies), as well as the complexity involved in detonating a nuclear weapon, would make it difficult for state sponsors to remain hidden (Lieber, 2016, pp. 101-104). For these reasons, I limited my analysis to nation actors only.

Definition of Nation-State and Role of Non-State Actors

There are many definitions for nation-state, usually referring to a politically legitimate government that exercises control over a territory, sovereign or otherwise. For purposes of this analysis, I looked at the political legitimacy of the nation-state as recognized by other nation-states. I use the term "nation-state" to mean a legitimate central government as recognized by the international community of other nation-states (Buzan & Waever, 2003, p. 66). For my model to work, I also needed a definition that accounts for an international relations perspective. For instance, while some may equate the Islamic State of Iraq and Syria (ISIS) and the United States of America as being states, the former is lacking in political legitimacy. To this end, I chose to follow the Montevideo Convention definition, which defines the state as the following: "The state as a person of international law should possess the following qualifications: a) a permanent population; b) a defined territory; c) government; and d) capacity to enter into relations with the other states" (League of Nations, 1936, Art. 1).

Based on Jo and Gartzke's analysis (2007) and Fuhrmann, et al.'s Nuclear Latency dataset (2016), I have assumed that only states (as defined above) are capable of producing nuclear munitions. While such states may provide non-state actors with munitions and technology, the act of building nuclear munitions is still limited to state

actors. Furthermore, deploying sophisticated nuclear munitions also requires technologies that may be difficult for non-state actors to acquire without the help of a state actor. Therefore, I assume that even if the act of deploying and using a nuclear armament maybe undertaken by a non-state actor, that actor acts with the help of, or as a proxy of, a state actor. Therefore, again, my analysis is limited only to state actors. I also explore this rationale in more detail in Chapter IX.

Definition of Institution

As this thesis explores institutional ownership of nuclear munitions, I need to define what constitutes an institution. While I will offer a basic definition for purposes of analysis, I will revisit this definition later and refine it based on the outcome of my analysis. In the context of this analysis, an institution can be defined as a multilateral, global organization that operates in a democratic manner with the full consent of its participating members. If an institution is to own nuclear armaments, then such an institution cannot be seen as a "puppet" of any one nation-state (e.g., the United Nations is often perceived as being controlled by the United States) and would therefore need to operate independent of any one nation-state. Such an institution also needs to provide an incentive to both dismantle existing munitions as well as provide the security that is offered by nuclear armaments. Additional qualifications to help legitimize the institution and other requirements will be discussed in Chapters XI and XII.

Applicability of Deterrence Theory

Deterrence theory assumes that unitary actors, acting rationally, refrain from using nuclear weapons for self interest (Price & Tannenwald, 1996). For purposes of this

analysis, I chose to subscribe to this worldview. While there may be normative factors, I consider them extraneous to this analysis. I also look at other deterrence options in Chapter IX, such as deterrence through attribution, diplomacy, and deal making.

Chapter IV

Proposed Approach for Analysis

As discussed in Chapter II, there are three key steps to consider regarding nuclear munitions: Acquisition, Use, and Retaliation. I have categorized nation-states based on seven key capabilities required to produce nuclear munitions. Using these, I established a probability distribution of acquisition. This is the primary determinant of whether or not a nation-state is capable of acquiring nuclear weapons, before use or retaliation. Likewise, for Use and Retaliation, I used a normal or Gaussian distribution on the stability index, and will use this as a proxy for rationality.

In all of my analyses, the probabilities are joint and conditional—i.e., if the probability of Acquisition is 0.5 and the probability of Use is 0.3, then the conditional probability of Use is 0.15 since I assume Acquisition as an *a priori* requirement for Use. Similarly, if the probability of Retaliation is 0.4 in this scenario, then the total probability of Retaliation is 0.06. Therefore, while individual probabilities may seem high, the joint probability of Acquisition, Use, and Retaliation in a given scenario would be significantly lower.

Rather than go with an affirmative approach, the probabilistic model creates a spectrum spanning the likelihood of nuclear war. Using this framework, I evaluated five unique scenarios:

- State ownership of nuclear munitions
- Institutional and state ownership of nuclear munitions, with the rationality of the institution as the median for the rationality of the participating nation-states, where countries may still access their nuclear munitions
- Institutional and state ownership of nuclear munitions, with the rationality of the institution as the median of the rationality of the participating nation states, where countries have surrendered all access to their nuclear munitions but they remain nuclear capable
- Institutional and state ownership of nuclear munitions, with the rationality of the institution as the rationality of the most rational participating nation-state, where countries have surrendered all access to their nuclear munitions but are still nuclear capable
- Institution-only ownership of nuclear munitions, with the rationality of the institution being the rationality of the most rational participating nation state, where only the institution is nuclear-capable

I used a game theory payoff model to understand whether or not an institutional model of cooperation is even logical for states. In each of the five scenarios, I also used an optimization function to maximize the likelihood of nuclear war. Therefore, I will explore what the maximum probability of nuclear war is in the national ownership scenario versus the institutional ownership scenario, and use that as the basis for my recommendation.

Chapter V

The Likelihood of States Giving Up Their Nuclear Munitions: An Iterative Prisoner's Dilemma Analysis

The hypothesis of this thesis is that an institutional ownership model for nuclear munitions would result in safer outcomes globally. However, I also wanted to evaluate this assumption through a lens of realism: how feasible is it for nation-states to immediately give up their nuclear munitions to a single institution? In search of answers, I ran an iterated prisoner's dilemma simulation (written in JavaScript) in a two-player model. My goal in running this simulation was to understand whether or not a fully cooperative model made sense in a payoff matrix, and whether or not nation-states had more to gain from a retaliatory stance. I used the following payoff matrix (see Figure 4), where:

- defection is the most beneficial (5 points),
- mutual cooperation is somewhat beneficial (3 points),
- mutual defection is not very beneficial (1 point),
- cooperation while the other party defects is not at all beneficial (0 points).

I observed outcomes even in instances where I altered the actual values but kept intent the same.

		Player 2 Actions	
		Cooperate	**Renege**
Player 1 Actions	**Cooperate**	3.3 points	0.5 points
	Renege	5.0 points	1.1 point

Fig. 4. Payoff matrix for the model

Any player can take one of four stances:

- Always Cooperate: regardless of the actions of the other player, always cooperate
- Always Renege: regardless of the actions of the other player, always renege or defect
- Tit for Tat: mirror the other player's choice
- Adaptive: cooperate and defect in successive numbers (e.g., ten successive cooperations), repeat choices that resulted in the best outcome.

Table 7 shows the payoff rank-ordered by mutual outcomes. Ten thousand iterations were run for each simulation, with a 1% randomness variable introduced. Duplicate outcomes were removed (e.g., Always Cooperate/Always Renege has an outcome similar to Always Renege/Always Cooperate).

As can be seen, a Tit-for-Tat approach is much more beneficial to both parties. However, an Always Cooperate approach is also beneficial, only slightly less so than a mutually Tit-for-Tat approach. Since the Always Cooperate scenario emerged as one of the top contenders in a two-player system, I assumed that it may be in the best interest of at least one nation-state to give up its nuclear munitions.

Table 7. Payoff rank ordered by mutual outcomes

Player 1 strategy	Player 2 strategy	Player 1 outcome	Player 2 outcome	Mutual outcome
Tit for Tat	Tit for Tat	60%	60%	100%
Always Cooperate	Tit for Tat	60%	60%	100%
Always Cooperate	Always Cooperate	58%	60%	99%
Adaptive	Adaptive	56%	56%	93%
Adaptive	Tit for Tat	55%	55%	92%
Always Cooperate	Adaptive	7%	95%	85%
Always Cooperate	Always Renege	0%	100%	83%
Always Renege	Adaptive	29%	17%	39%
Always Renege	Tit for Tat	21%	19%	34%
Always Renege	Always Renege	20%	20%	33%

How would this work in a nine-player system (i.e., all declared and *de facto* nuclear states: United States, Russia, United Kingdom, France, China, India, Pakistan, Israel, and South Africa)? Szilagyi (2003) evaluated an N-person prisoner's dilemma and found that in a multi-player Pavlovian system, a high degree of equilibrium was reached when both cooperators and defectors had the same outcome (p. 162). What does this mean in my analysis? I need to show the same outcome (i.e., Use) for all participating states.

In the next two scenarios with institutional ownership, I assumed that nation-states that currently own nuclear munitions would continue to own them, independent of institutional ownership (i.e., Acquire would remain unchanged). However, as seen in the payoff model (Table 7, above), it is in the best interest of nation-states to cooperate.

Indeed, one must question the value of an institution if the nation-states and the institution retain the right to use nuclear munitions. Therefore, I assumed that they may possibly delegate the right to use the nuclear munitions to the institution.

Axelrod's Theory of Cooperation

Robert Axelrod (1984) conducted tournaments of iterated prisoner's dilemma, and found four properties that were successful:

> The analysis of the data from these tournaments reveals four properties which tend to make a decision rule successful: avoidance of unnecessary conflict by cooperating as long as the other player does, provocability in the face of an uncalled for defection by the other, forgiveness after responding to a provocation, and clarity of behavior so that the other player can adapt to your pattern of action. (p. 20)

Axelrod found that overall, cooperative strategies performed best. However, in order to prevent a scenario from being fooled by the other player, there needs to be an element of retaliation backed by a realistic threat. As such, Tit-for-Tat strategies were ultimately the most successful; specifically, the most effective outcome was when a player cooperated at first and subsequently mimicked the actions of the other player.

It is worth noting that nuclear deterrence and preventing nuclear wars are not zero-sum games. In zero-sum strategies, there are finite resources available. But as I discussed earlier, one of the primary purposes of nuclear munitions is credible defense. Muhammet Bas and Andrew Coe (forthcoming, p. 36) also note that the existence of nuclear munitions is more significant than the quantities of nuclear munitions for understanding their effects on balance of power. Therefore, when it comes to ownership of nuclear munitions, the threat is just as effective coming from one country or ten countries. Sharing the same nuclear munitions across multiple countries in no way

diminishes the threat as long as retaliation is seen as provocable. In terms of preventing nuclear war, there is a net positive in cooperation (i.e., shared defenses; mitigated outcomes of nuclear war), but defection could have much worse consequences (i.e., increased risk of attack, retaliation, and global nuclear war). Therefore, if a nation-state or a group of nation-states are seen as always "nice" or always cooperative, then the other party could easily take advantage. Therefore, it is in the best interest of any state or institution to be cooperative but also to convince the other states that provocation will be met with retaliation.

Noise in the System

While these are the underlying assumptions of my analysis, it is also worth pointing to the research conducted by Bas and Coe (2016), in which they examine development of nuclear weapons by one state and imperfect observations by another state, and conclude that a significant amount of the variation could be attributed to chance. The authors also note that there is uncertainty involved in assessing the duration to build nuclear capability, estimating the progress of a state's nuclear capability, as well as the consequential outcome of a pre-emptive attack (even though their model primarily focuses on the first two scenarios).

In their model, they observe that deal equilibria only exist under a certain set of conditions (e.g., when progress can be adequately observed) while no-deal equilibria always exists (almost as a default). Therefore, while I assumed and introduced a conservative 1% randomness, and a near-perfect observation of cooperation and renegation for all the scenarios, the realistic outcomes would have a chance to play a much bigger role.

Furthermore, Bas and Coe (2016) hypothesize and prove that in 40 of 66 cases, intelligence estimates were based on the progress of nuclear capability, not existence (p. 23). Therefore, while I assume perfect observation and reciprocity (e.g., Tit-for-Tat), in reality, acting on cooperation or renegation would be much more variable. The authors also distinguish between the likelihood of conflict and proliferation: while better observation may decrease the likelihood of conflict, it may not affect proliferation; however, delays in gathering the right information could encourage proliferation as an unintended consequence (pp. 34, 37). In my model, improved intelligence capabilities would then impact use and retaliation probabilities (i.e., Conflict), while delays in ensuring "perfect observation" could potentially expedite acquisition.

When I added a high degree of random intervention (20-30%) as a proxy for noise for one of the players, I found that the effect on the outcomes was relatively less prominent in cooperative strategies (i.e., delta of ~ ±2-10% for mutual outcomes in Always Cooperate, Tit for Tat, or Adaptive) and much more pronounced in defection strategies (i.e., delta of ~ ±5-20% for mutual outcomes in Always Renege). This means that cooperation or adaptive strategies work better for mutual outcomes even in imperfect information scenarios.

Grim Triggers

As I discussed earlier and I also noticed in my simulations, defection tends to have an overall poor payout as an outcome, both at the individual and at the systemic level. Axelrod (1984) discusses James Friedman's concept of "Grim Trigger," which is a variation of defection where one player will always cooperate until the other defects. However, once the other player defects, our player will cease to cooperate and will

always defect. In this variation, I noticed that there is no "forgiveness after responding to a provocation," which Axelrod talks about (1984, p. 20). While it works as an extremely credible deterrent, it fails to account for two elements: noise in the system, and changes in circumstances of a given state.

Bas and Coe (2016) note that the stochasticity of many other variables could impact outcomes to a degree comparable to more obvious factors such as "costs of war or balance of power." If this is the case, then a "Grim Trigger" would need a very robust and near-perfect observation to be effective. Any noise in the system resulting in a "Grim Trigger" would result in suboptimal payouts for all parties. Indeed, even if the trigger were warranted based on perfect observation, it still fails to account for changes in international dynamics and balance of power. After all, nation-states are not monolithic entities; they are affected by both internal machinations and externalities. Changes in domestic and international politics, economic incentives, and social movements could each/all alter how nation-states behave.

The "Grim Trigger" also violates Axelrod's (1984) requirement of "forgiveness" after responding to a provocation if one is to maximize mutual payout. Therefore, while a "Grim Trigger" outcome may result in better payouts for the nation-state and achieve equilibrium, it would nevertheless be myopic for mutual benefit and not create incentive for better actions in the future.

Reaching Equilibrium

In a theoretical model of Prisoner's Dilemma, certain states of equilibrium are not possible. For instance, Always Cooperate will likely result in exploitation and upset the equilibrium, while Always Defect will always result in equilibrium. However, Tit-for-Tat or Adaptive strategies with a cooperative bent always yield relatively high payouts, even in the presence of systemic noise. Defection strategies, while helping achieve equilibrium, have significantly lower mutual payouts.

In practical terms, this means that nation-states and institutions cannot afford to be rigid in their approach to nuclear munitions ownership and use. The ability to be adaptive and respond in kind, while aiming for long-term cooperation, is arguably the best approach on which to base the institution model.

Limitations of the Model

My model does not account for individual optimality of a nation-state, only aggregate optimality, since I seek to minimize the overall probability of nuclear weapons use. This is discussed in greater detail in Chapter XI. I also assume near-perfect observation in all the scenarios, and I did not account for noise in any meaningful way in calculating probabilities. I also have not accounted for the quantity of nuclear weapons, but only the presence of nuclear weapons. It is quite possible that the number of munitions increases the ability to more successfully deliver them, but this is not factored in my analysis.

Chapter VI

State Ownership of Nuclear Munitions

The objective of the scenario of state ownership of nuclear munitions is to accurately portray the current state of nuclear munitions capabilities. I used Jo and Gartzke's (2007) analysis in combination with the Fuhrmann nuclear latency dataset (2016) and the composite rationality proxy for input sources for my model (see Tables 8-11 below). In each table,

% indicates the probability or distribution percentage,

NS represents the composite nuclear munitions capability score from the Jo-Gartzke nuclear munitions capability index, and

N represents the number of states.

Table 8. Probability of Acquisition of states: Percentage distribution of states based on nuclear capability from the Jo-Gartzke nuclear munitions capability index.

	P (Acquire)- Distribution % with nuclear scores and number of states						
	Very high	High	Medium	Low	Very low	Trivial	Total
%	15%	12%	13%	8%	31%	22%	100%
NS	7	6	4 and 5	3	1 and 2	0	
N	29	22	24	16	58	41	190

The table above then gets updated to the following:

Table 9. Updated probability of acquisition of states: Updated percentage distribution of states based on nuclear capability with updated Fuhrmann latency index.

	P (Acquire)- Distribution % with nuclear scores and number of states						
	Very high	High	Medium	Low	Very low	Trivial	Total
%	16%	12%	12%	8%	31%	22%	100%
N	29 + 2	22	24 – 2	16	58	41	190

Table 10. Probability of Use of nuclear munitions of states

	P (Use)- Distribution % with nuclear scores and number of states						
	Very high	High	Medium	Low	Very low	Trivial	Total
%	4%	27%	41%	19%	9%	0%	100%
N	8	51	78	36	17	0	190

Table 11. Probability of Retaliation using nuclear munitions of states

	P (Retaliation)- Distribution % with nuclear scores and number of states						
	Very high	High	Medium	Low	Very low	Trivial	Total
%	4%	27%	41%	19%	9%	0%	100%
N	8	51	78	36	17	0	190

Source: thesis author

Then I calculated the joint probabilities for Acquisition, Use, and Retaliation to produce the likelihood of each of those scenarios. Tables 12(a) and 12(b) below show the joint probabilities of Acquire and Use for a scenario of national ownership of nuclear

munitions. Based on the distribution of probabilities, there is a 0.65% chance that nuclear munitions will be used based on the current capabilities and world stability index.

Table 12(a). Probability of Use and Acquisition in a state-owned scenario

	P (Acquire) %				
P (Use) %	Very high	High	Medium	Low	Very low
Very high	0.65%	0.46%	0.46%	0.34%	1.22%
High	4.41%	3.13%	3.13%	2.27%	8.24%
Medium	6.69%	4.75%	4.75%	3.45%	12.52%
Low	3.10%	2.20%	2.20%	1.60%	5.80%
Very Low	1.47%	1.04%	1.04%	0.76%	2.75%

Table 12(b). Number of states likely to Acquire and Use in a state-owned scenario

	P (Acquire) N				
P (Use) N	Very high	High	Medium	Low	Very low
Very high	1.24	0.88	0.88	0.64	2.32
High	8.37	5.94	5.94	4.32	15.66
Medium	12.71	9.02	9.02	6.56	23.78
Low	5.89	4.18	4.18	3.04	11.02
Very Low	2.79	1.98	1.98	1.44	5.22

Gartzke and Kroenig (2009) suggest that the debate as to whether or not nation-states want to become nuclear powers is irrelevant if they lack the ability to acquire the necessary technology. Thus, I retained the "Trivial" column for Acquisition but not for Use or Retaliation.

Likewise, based on the probability distribution above, I calculated the probability of Retaliation. However, for Retaliation to occur, both Use and Acquisition should have occurred first. If there is a nuclear retaliation to a non-nuclear attack, then I consider that to be first use and not retaliation. The color codes highlight the probabilities that were grouped similarly. For instance, in the Use and Acquisition table in Table 12(a) (see above), the 0.65% cell in dark red is shown in the Very High probability column in the Use, Acquire, and Retaliation table below in Table 13(a).

Table 13(a). Probability of Use, Acquisition, and Retaliation in a state-owned scenario

	P (Acquire) * P (Use) %				
P (Retaliation) %	Very high	High	Medium	Low	Very low
Very high	0.65%	0.32%	0.79%	0.61%	1.39%
High	0.18%	2.16%	5.34%	4.09%	9.41%
Medium	0.27%	3.28%	8.11%	6.22%	14.28%
Low	0.12%	1.52%	3.76%	2.88%	6.62%
Very Low	0.06%	0.72%	1.78%	1.36%	3.14%

Table 13(b). Number of states likely to Acquire, Use, and Retaliate in a state-owned scenario

	P (Acquire) * P (Use) N				
P (Retaliation) N	Very high	High	Medium	Low	Very low
Very high	0.05	0.61	1.50	1.15	2.65
High	0.33	4.10	10.14	7.78	17.87
Medium	0.51	6.23	15.40	11.81	27.14
Low	0.24	2.89	7.14	5.47	12.58
Very Low	0.11	1.37	3.38	2.59	5.96

I calculated retaliation P (Retaliation) as P (Use | Attacked), therefore;

$$P(\text{Retaliation}) = \frac{[P(\text{Use} \mid \text{Attacked}) * P(\text{Use} \mid \text{Acquisition})]}{\sum P(\text{Attacked})}$$

I assumed that $\sum P(\text{Attacked}) = 1$, therefore the probability of retaliation would be:

$$P(\text{Retaliation}) = [P(\text{Use}) * P(\text{Use} \mid \text{Acquisition})]$$

This approach indicates that while 16% of nation-states may have nuclear munitions capabilities (either declared, *de facto*, or near-capable), the probability of use is only 0.65% (or 1.24 states); the probability of retaliation after use is only 0.03% in a state-owned scenario (or 0.05 state). I use this as the baseline and compare this to scenarios based on institution ownership.

I was not surprised to find that when I incorporated the Nuclear Latency data from Fuhrmann, it exacerbated use and retaliation. For example, the probability of acquisition and use jumped from 1.0% to 1.1%, with a tangible effect on the number of nations

acquiring and using jumping from 1.94 to 2.08. Correspondingly, retaliation jumped from 0.13 nation-states to 0.14 nation-states. However, as I updated my rationality index, and changed the criteria for rationality from just (Stability) to (Stability, Government Effectiveness, Rule of Law, and Control of Corruption), these numbers subsequently dropped to 0.04% and 0.08 states, respectively.

Chapter VII

Institutional and State Ownership of Nuclear Munitions: Median Rationality

In this scenario, I explore only institutional ownership of nuclear munitions. I assume that 28 of the current nation-states with a score of 7 in the Jo-Gartzke nuclear munitions capability index, and any others included in the Fuhrmann nuclear latency dataset, will hand over their nuclear munitions to an institution. However, the institution itself will be a new addition, with no known rationality index. Therefore, the total number of considered entities for my analysis drops from 190 to 163. However, I assume that the probability of Acquisition remains unchanged, i.e., even if a nation-state hands over its nuclear armaments to an institution, it is still capable of building more if necessary.

While an institution may own nuclear munitions, how is its rationality gauged? On one hand, an institution that can be swayed in any direction by its member countries would be quite unstable; on the other hand, an institution that would not take any action would be ineffective. In this scenario, I assume that the rationality of the institution owning the nuclear munitions would be the median rationality of its participating nation-states.

To understand what this might be, I isolated the countries considered nuclear-capable in my list, evaluated their composite scores, and used stability as the leading indicator. The most stable of these was Finland, ranked #8, while the least stable was Pakistan ranked #185. The mean stability was ~98, while the median stability was 85. Given that the stability index is in rank order, mean is less useful for evaluating

composite stability, whereas median provides a reasonable mid-point of the number of countries on either side. A clustered approach would also have been possible, but the analysis identified five separate clusters (37, 73, 94, 120, and 175).

I also calculated the composite scores for all the nuclear-capable countries (composite scores, as before, include Political Stability, Effectiveness of Government, Rule of Law, and Control of Corruption). Rank ordering based on composite scores showed Finland ranked first at 7.6, and Pakistan last at –4.78, with a mean composite score of 1.03 and a median composite score of 0.2. The mean score was on par with Micronesia (0.97), Namibia (1.09), and Italy (1.11), and the median score on par with Romania (0.09), Jordan (0.2), Tonga (0.29), and South Africa (0.3). In all three instances (i.e., median stability rank ordering, composite mean, and composite median), the institution falls in the Medium rationality bucket (–1.99 to + 1.99 in Table 4 and Table 5). Please note that the purpose of the above analysis is to estimate where the institution would fall in my rationality categories. While I used the aforementioned analysis to place the institution in the Medium category for purposes of my scenario, arguments could be made to place it elsewhere.

In Table 14(a), 14(b), 15, and 16 below, percent (%) indicates the probability or distribution percentage, similar to the state-owned scenario. In the Acquire step (Table 14), I added the institution to the Very High category since the institution would own nuclear munitions. In both Use and Retaliation steps (Tables 15 and 16), I added the institution to the "Medium" category based on the median placement of rationality. I also added the institution as a "+1" to the counts in the appropriate category (i.e., under "Very High" for Acquire, and under "Medium" for Use and Retaliation).

Table 14(a). Acquire step

	P (Acquire)- Distribution % with nuclear scores and number of states						
	Very high	High	Medium	Low	Very low	Trivial	Total
%	15%	12%	13%	8%	31%	22%	100%
NS	7	6	4 and 5	3	1 and 2	0	
N	29 + 1	22	24	16	58	41	190 + 1

However, the addition of countries from the Fuhrmann Nuclear Latency index moves the total number up by two in the Very High category (South Africa and Netherlands).

Table 14(b). Acquire step, plus countries from Nuclear Latency index added

	P (Acquire)- Distribution % with nuclear scores and number of states						
	Very high	High	Medium	Low	Very low	Trivial	Total
%	17%	12%	12%	8%	31%	22%	100%
N	29 + 1 + 2	22	24 – 2	16	58	41	190 + 1

Furthermore, the distribution of Use also changes when we remove those countries with nuclear weapons from the Use table and add the institution in their place.

Table 15. Use step

	P (Use)- Distribution % with nuclear scores and number of states						
	Very high	High	Medium	Low	Very low	Trivial	Total
%	4%	27%	41%	19%	9%	0%	100%
N	8	51	78 + 1	36	17	7	190 + 1

Table 16. Retaliation step

	P (Retaliation)- Distribution % with nuclear scores and number of states						
	Very high	High	Medium	Low	Very low	Trivial	Total
%	4%	27%	41%	19%	9%	0%	100%
N	8	51	78 + 1	36	17	0	190 + 1

As before, I calculated the probability of Acquisition and Use (Figure 17(a)) as well as the probability of Acquisition, Use, and Retaliation (Figure 17(b)).

Table 17(a). Probability of Use and Acquisition in an institution-owned scenario, where institutional rationality is the median of participating state rationality

	P (Acquire) %				
P (Use) %	Very high	High	Medium	Low	Very low
Very high	0.67%	0.46%	0.46%	0.34%	1.21%
High	4.52%	3.11%	3.11%	2.26%	8.20%
Medium	6.87%	4.72%	4.72%	3.43%	12.45%
Low	3.18%	2.19%	2.19%	1.59%	5.77%
Very Low	1.51%	1.04%	1.04%	0.75%	2.73%

Table 17(b). Number of states likely to Acquire and Use in an institution-owned scenario, where institutional rationality is the median of participating state rationality.

	P (Acquire) N				
P (Use) N	Very high	High	Medium	Low	Very low
Very high	1.27	0.88	0.88	0.64	2.31
High	8.59	5.91	5.91	4.30	15.58
Medium	13.05	8.97	8.97	6.53	23.66
Low	6.05	4.16	4.16	3.02	10.96
Very Low	2.86	1.97	1.97	1.43	5.19

When I examine the difference between this scenario and the state-ownership scenario, there is a both a slight increase (high risk) and a slight drop (low risk) in probabilities. This is because the probability distribution of Acquisition remains

unchanged for the states, but has been exacerbated by the addition of the institution. Furthermore, the distribution of Use and Retaliation has changed. The delta in probabilities is reflected in Tables 18(a) and (b).

Table 18(a). Difference in probability of Use and Acquisition in state vs. institution-owned scenarios, where institutional rationality is median of participating state rationality

	P (Acquire) %				
P (Use) %	Very high	High	Medium	Low	Very low
Very high	0.02%	0.00%	0.00%	0.00%	-0.01%
High	0.14%	-0.02%	-0.02%	-0.01%	-0.05%
Medium	0.21%	-0.03%	-0.03%	-0.02%	-0.08%
Low	0.10%	-0.01%	-0.01%	-0.01%	-0.04%
Very Low	0.05%	-0.01%	-0.01%	0.00%	-0.02%

Table 18(b). Difference in number of Use and Acquisition states in state vs. institution-owned scenarios, where institutional rationality is median of participating state rationality

	P (Acquire) N				
P (Use) N	Very high	High	Medium	Low	Very low
Very high	0.03	0.00	0.00	0.00	-0.01
High	0.22	-0.03	-0.03	-0.02	-0.08
Medium	0.34	-0.05	-0.05	-0.03	-0.12
Low	0.16	-0.02	-0.02	-0.02	-0.06
Very Low	0.07	-0.01	-0.01	-0.01	-0.03

Similarly, I also calculated the probability of Retaliation in an institution-owned scenario with median participant rationality (see Tables 19(a) and (b), as well as the corresponding delta (see Tables 20(a) and (b).

Table 19(a). Probability of Use, Acquisition, and Retaliation in an institution-owned scenario, where institutional rationality is median of participating state rationality

	P (Acquire) * P (Use) %				
P (Retaliation) N	Very high	High	Medium	Low	Very low
Very high	0.1%	0.5%	1.3%	1.2%	2.2%
High	0.2%	1.8%	4.6%	4.2%	8.0%
Medium	0.4%	2.7%	7.1%	6.6%	12.5%
Low	0.2%	1.8%	4.6%	4.2%	8.0%
Very Low	0.1%	0.5%	1.3%	1.2%	2.2%

Table 19(b). Number of states likely to Acquire, Use, and Retaliate in an institution-owned scenario, where institutional rationality is median of participating state rationality

	P (Acquire) * P (Use) N				
P (Retaliation) N	Very high	High	Medium	Low	Very low
Very high	0.13	0.93	2.41	2.21	4.22
High	0.47	3.34	8.69	8.00	15.24
Medium	0.74	5.25	13.65	12.56	23.93
Low	0.47	3.34	8.69	8.00	15.24
Very Low	0.13	0.93	2.41	2.21	4.22

Table 20(a). Difference in probability of Use, Acquisition, and Retaliation in state vs. institution-owned scenarios, where institutional rationality is the median of participating state rationality.

	P (Acquire) * P (Use) %				
P (Retaliation) %	Very high	High	Medium	Low	Very low
Very high	0.04%	0.2%	0.5%	0.6%	0.8%
High	0.07%	-0.4%	-0.8%	0.1%	-1.4%
Medium	0.11%	-0.6%	-1.0%	0.3%	-1.7%
Low	0.12%	0.2%	0.8%	1.3%	1.4%
Very Low	0.01%	-0.2%	-0.5%	-0.2%	-0.9%

Table 20(b). Difference in number of Use, Acquisition, and Retaliation states in state vs. institution owned scenarios, where institutional rationality is median of participating state rationality

	P (Acquire) * P (Use) N				
P (Retaliation) N	Very high	High	Medium	Low	Very low
Very high	0.08	0.31	0.90	1.06	1.58
High	0.13	-0.81	-1.51	0.21	-2.56
Medium	0.22	-1.06	-1.84	0.73	-3.10
Low	0.23	0.42	1.51	2.52	2.71
Very Low	0.02	-0.46	-0.99	-0.38	-1.71

Similar to Use and Acquisition, I noticed a slight increase in the number of countries likely to engage in Retaliation. Surprisingly, the delta becomes negative in countries that are less likely to Acquire and Use (e.g., "Medium" and "High" columns in Table 20(b)). This scenario tells me that the outcomes from both Use and Retaliation are marginally more dangerous in an institution-owned scenario, stemming from adding the institution to the countries in play.

Then I asked: could I improve upon the stability if I removed the nation-states from play? I explored a variation of this scenario, where the distribution of Acquisition remained the same (Table 21(a), but the distribution of Use was updated to exclude those nations with nuclear capabilities (i.e., they relegate their Use to the institution) (Table 21(b). In this scenario, the distribution of probability of Use and Retaliation looked different:

Table 21(a). Difference in probability of Use and Acquisition in state vs. institution owned scenarios, where institutional rationality is median of participating state rationality and distribution of Use excludes countries that have surrendered their munitions to the institution

	P (Acquire) %				
P (Use) %	Very high	High	Medium	Low	Very low
Very high	0.06%	0.02%	0.02%	0.02%	0.07%
High	-0.57%	-0.49%	-0.49%	-0.36%	-1.29%
Medium	-0.72%	-0.64%	-0.64%	-0.47%	-1.70%
Low	-0.68%	-0.54%	-0.54%	-0.39%	-1.42%
Very Low	-0.33%	-0.26%	-0.26%	-0.19%	-0.69%

Table 21(b). Difference in number of Use and Acquisition states in state vs. institution owned scenarios, where institutional rationality is median of participating state rationality and distribution of Use excludes countries that have surrendered their munitions to the institution.

	P (Acquire) N				
P (Use) N	Very high	High	Medium	Low	Very low
Very high	0.11	0.05	0.05	0.03	0.12
High	-1.09	-0.93	-0.93	-0.68	-2.46
Medium	-1.38	-1.23	-1.23	-0.90	-3.25
Low	-1.30	-1.03	-1.03	-0.75	-2.71
Very Low	-0.63	-0.50	-0.50	-0.36	-1.31

I also calculated the probability of Retaliation in an institution-owned scenario with median participant rationality, where countries that have surrendered their nuclear munitions are excluded from the distribution. The corresponding delta is shown in Tables 22(a) and (b) below.

Table 22(a). Difference in probability of Use, Acquisition, and Retaliation in state vs. institution-owned scenarios, where institutional rationality is median of participating state rationality and participating countries surrender their munitions to the institution.

	P (Acquire) * P (Use) %				
P (Retaliation) %	Very high	High	Medium	Low	Very low
Very high	0.009%	0.0%	0.1%	0.0%	0.0%
High	0.02%	-0.3%	-0.7%	-0.8%	-1.6%
Medium	0.03%	-0.4%	-0.8%	-1.1%	-2.2%
Low	0.00%	-0.3%	-0.8%	-0.8%	-1.7%
Very Low	0.00%	-0.2%	-0.4%	-0.4%	-0.8%

Table 22(b). Difference in number of Use, Acquisition, and Retaliation states in state vs. institution owned scenarios, where institutional rationality is median of participating state rationality and participating countries surrender their munitions to the institution.

	P (Acquire) * P (Use) N				
P (Retaliation) N	Very high	High	Medium	Low	Very low
Very high	0.02	0.05	0.14	0.01	0.08
High	0.03	-0.53	-1.28	-1.52	-3.13
Medium	0.06	-0.68	-1.61	-2.08	-4.20
Low	-0.01	-0.64	-1.56	-1.54	-3.29
Very Low	0.00	-0.31	-0.75	-0.74	-1.59

I noticed a dramatic drop in the Use scenario more or less across the board, except in the case of high probability Acquisition and Use. This is understandable, because as long as countries can acquire, the addition of the institution exacerbates the high-risk scenarios while mitigating all other scenarios.

Chapter VIII

Institutional and State Ownership of Nuclear Munitions: High Rationality

In the scenario presented in the previous chapter, I noticed that an institution-owned model was only slightly better than a state-owned model. As I explored the root cause of this discrepancy, I realized that an effective and stable institution may help reduce risk in an institutional model. What if I designed an institution that is as stable as its most stable and rational participating country? Exploring the list of countries with the highest Jo-Gartzke nuclear munitions capability scores, the highest would be Finland, which ranks #8 in the Global Stability index, a Political Stability index of 1.28, a Government Effectiveness index of 2.02, a Control of Corruption index of 2.18, and a composite score of 5.48. All of these factors places the institution in the "highly rational" category of distribution.

In the tables below, the following conventions apply:

- percent (%) indicates the probability or distribution percentage
- NS represents the composite nuclear munitions capability score from the Jo-Gartzke nuclear munitions capability index
- N represents the number of states.

In the Acquire step, I added the institution to the Very High category since the institution would own nuclear munitions. However, in both the Use and Retaliation steps, I added the institution to the "Very Low" category based on the high stability and rationality placement (i.e., the stability and composite index of the most stable

participating state, Finland, would put the institution in the "Very Low" category). Similar to the previous scenario, I also added the institution as a "+1" to counts in the appropriate category (i.e., under "Very High" for Acquire, and under "Very Low" for Use and Retaliation).

Table 23. Probability of Acquisition of states and institution: Percentage distribution of states based on nuclear capability from the Jo-Gartzke nuclear munitions capability index

	P (Acquire)- Distribution % with nuclear scores and number of states						
	Very high	High	Medium	Low	Very low	Trivial	Total
%	15%	12%	13%	8%	31%	22%	100%
NS	7	6	4 and 5	3	1 and 2	0	
N	29 + 1	22	24	16	58	41	190 + 1

However, the addition of the Nuclear Latency index moves the total number up by two more in the Very High category (with South Africa and Netherlands added).

Table 24. Updated probability of Acquisition of states and institution: Updated percentage distribution of states based on nuclear capability with updated Fuhrmann latency index

	P (Acquire)- Distribution % with nuclear scores and number of states						
	Very high	High	Medium	Low	Very low	Trivial	Total
%	17%	12%	12%	8%	30%	21%	
N	29 + 1 + 2	22	24 – 2	16	58	41	190 + 1

Based on the outcome of my previous results, I limited Use to only the institution and excluded those nations that have relegated the use of their munitions to the institution. The distribution was updated accordingly.

Table 25. Probability of Use

	P (Use)- Distribution %						
	Very high	High	Medium	Low	Very low	Trivial	Total
%	5%	27%	42%	18%	9%	0%	100%

Table 26. Probability of Retaliation

	P (Retaliation)- Distribution %						
	Very high	High	Medium	Low	Very low	Trivial	Total
%	5%	27%	42%	18%	9%	0%	100%

Similar to my previous scenarios, I calculated the probability of acquisition and use (Table 27(a)), and the number of states likely to Acquire and Use (Table 27(b)).

Table 27(a). Probability of Use and Acquisition in an institution-owned scenario, where institutional rationality is that of the most rational and stable participating state

	P (Acquire) %				
P (Use) %	Very high	High	Medium	Low	Very low
Very high	0.83%	0.57%	0.57%	0.42%	1.54%
High	4.50%	3.09%	3.09%	2.25%	8.30%
Medium	7.00%	4.81%	4.81%	3.50%	12.91%
Low	2.83%	1.95%	1.95%	1.42%	5.22%
Very Low	1.33%	0.92%	0.92%	0.67%	2.46%

Table 27(b). Number of states likely to Acquire and Use in an institution owned scenario, where institutional rationality is that of the most rational and stable participating state

	P (Acquire) N				
P (Use) N	Very high	High	Medium	Low	Very low
Very high	1.34	0.92	0.92	0.67	2.47
High	7.25	4.98	4.98	3.62	13.36
Medium	11.27	7.75	7.75	5.64	20.78
Low	4.56	3.14	3.14	2.28	8.41
Very Low	2.15	1.48	1.48	1.07	3.96

Much like the previous institutional ownership scenario, there is a drop in probabilities here as well, stemming from a relative change in stability. Once again, it is worth bearing in mind that while the absolute probability distribution itself may be unchanged, the relative number of impacted states will have changed as a result of the addition of the institution. Therefore, the resulting probability distribution as a calculated percentage of this drop will also have changed. This delta is reflected below.

Table 28(a). Difference in probability of Use and Acquisition in state vs. institution owned scenarios, where institutional rationality is that of the most rational and stable participating state

	P (Acquire) %				
P (Use) %	Very high	High	Medium	Low	Very low
Very high	0.05%	0.02%	0.02%	0.02%	0.08%
High	-0.59%	-0.50%	-0.50%	-0.37%	-1.21%
Medium	-0.75%	-0.67%	-0.67%	-0.48%	-1.57%
Low	-0.70%	-0.55%	-0.55%	-0.40%	-1.37%
Very Low	-0.34%	-0.26%	-0.26%	-0.19%	-0.66%

Table 28(b). Difference in number of Use and Acquisition states in a scenario of states vs. institution-owned, where institutional rationality is that of the most rational and stable participating state.

	P (Acquire) N				
P (Use) N	Very high	High	Medium	Low	Very low
Very high	0.10	0.04	0.04	0.03	0.15
High	-1.13	-0.96	-0.96	-0.70	-2.30
Medium	-1.44	-1.27	-1.27	-0.93	-3.00
Low	-1.33	-1.04	-1.04	-0.76	-2.61
Very Low	-0.64	-0.50	-0.50	-0.37	-1.26

Similarly, I also calculated the probability of Retaliation (Table 29(a) and number of states (Table 29(b) in an institution-owned scenario with high stability, and the corresponding deltas (Table 30(a) and (b)).

Table 29(a). Probability of Use, Acquisition, and Retaliation in an institution-owned scenario, where institutional rationality is that of the most rational and stable participating state.

	P (Acquire) * P (Use) %				
P (Retaliation) %	Very high	High	Medium	Low	Very low
Very high	0.04%	0.4%	1.0%	0.7%	1.7%
High	0.23%	2.2%	5.5%	3.9%	9.2%
Medium	0.35%	3.4%	8.5%	6.0%	14.4%
Low	0.14%	1.4%	3.4%	2.4%	5.8%
Very Low	0.07%	0.7%	1.6%	1.1%	2.7%

Table 29(b). Number of states likely to Acquire, Use, and Retaliate in an institution-owned scenario, where institutional rationality is that of the most rational and stable participating state

	P (Acquire) * P (Use) N				
P (Retaliation) N	Very high	High	Medium	Low	Very low
Very high	0.07	0.66	1.63	1.15	2.76
High	0.36	3.55	8.82	6.22	14.89
Medium	0.56	5.52	13.72	9.68	23.16
Low	0.23	2.24	5.55	3.92	9.38
Very Low	0.11	1.05	2.61	1.84	4.41

Table 30(a). Difference in probability of Use, Acquisition, and Retaliation in state vs. institution owned scenarios, where institutional rationality is that of the most rational and stable participating state

	P (Acquire) * P (Use) %				
P (Retaliation) %	Very high	High	Medium	Low	Very low
Very high	0.009%	0.0%	0.1%	0.0%	0.1%
High	0.01%	-0.3%	-0.7%	-0.8%	-1.6%
Medium	0.03%	-0.4%	-0.9%	-1.1%	-2.1%
Low	0.00%	-0.3%	-0.8%	-0.8%	-1.7%
Very Low	0.00%	-0.2%	-0.4%	-0.4%	-0.8%

Table 30(b). Difference in number of Use, Acquisition, and Retaliation states in state vs. institution owned scenarios, where institutional rationality is that of the most rational and stable participating state.

	P (Acquire) * P (Use) N				
P (Retaliation) N	Very high	High	Medium	Low	Very low
Very high	0.02	0.05	0.13	0.00	0.11
High	0.03	-0.55	-1.32	-1.56	-2.98
Medium	0.06	-0.71	-1.68	-2.13	-3.97
Low	-0.01	-0.65	-1.58	-1.56	-3.20
Very Low	0.00	-0.32	-0.77	-0.75	-1.55

Unfortunately, I did not notice any meaningful drop in the numbers, because the shift in the stability was relatively minor while the Acquisition probabilities remained unchanged. While a more stable institution is certainly more preferable, maximizing for payoff shows there is not a tangible drop in risk for either Use or Retaliation. For instance, the probability of Retaliation decreased in some scenarios, but marginally increased in others.

This led me to a variation of the final scenario: would stability increase if all the states considered nuclear munitions-capable gave up all current and future access to nuclear munitions? It is not realistic to assume that they would not be able to acquire munitions at all, even in this scenario. So, those countries were moved to the "High" probability category of acquisition, while "Very High" was limited to just the institution.

The tables below capture the change in probabilities (Table 31(a)) and the actual number of states (Table 31(b)) in that variation. Tables 32(a) and (b) show the deltas.

Table 31(a). Difference in probability of Use and Acquisition in state-owned vs. institution-only owned scenarios, where institutional rationality is that of the most rational and stable participating state, and only the institution is nuclear-capable.

	P (Acquire) %				
P (Use) %	Very high	High	Medium	Low	Very low
Very high	-0.63%	0.70%	0.02%	0.02%	0.08%
High	-4.26%	3.17%	-0.50%	-0.37%	-1.21%
Medium	-6.47%	5.05%	-0.67%	-0.48%	-1.57%
Low	-3.01%	1.77%	-0.55%	-0.40%	-1.37%
Very Low	-1.43%	0.82%	-0.26%	-0.19%	-0.66%

Table 31(b). – Difference in number of Use and Acquisition states in state vs. institution-only owned scenarios, where institutional rationality is that of the most stable participating state.

	P (Acquire) N				
P (Use) N	Very high	High	Medium	Low	Very low
Very high	-1.20	1.34	0.04	0.03	0.15
High	-8.14	6.06	-0.96	-0.70	-2.30
Medium	-12.36	9.65	-1.27	-0.93	-3.00
Low	-5.75	3.38	-1.04	-0.76	-2.61
Very Low	-2.72	1.58	-0.50	-0.37	-1.26

Table 32(a). Difference in probability of Use, Acquisition, and Retaliation in state-owned vs. institution-only owned scenarios, where institutional rationality is that of the most rational and stable participating state, and only the institution is nuclear-capable.

	P (Acquire) * P (Use) %				
P (Retaliation) %	Very high	High	Medium	Low	Very low
Very high	-0.025%	0.1%	0.1%	0.0%	0.1%
High	-0.17%	-0.1%	-0.7%	-0.8%	-1.6%
Medium	-0.26%	-0.1%	-0.9%	-1.1%	-2.1%
Low	-0.12%	-0.2%	-0.8%	-0.8%	-1.7%
Very Low	-0.06%	-0.1%	-0.4%	-0.4%	-0.8%

Table 32(b). Difference in number of Use, Acquisition, and Retaliation states in state-owned vs. institution-only owned scenarios, where institutional rationality is that of the most rational and stable participating state, and only the institution is nuclear-capable.

	P (Acquire) * P (Use) N				
P (Retaliation) N	Very high	High	Medium	Low	Very low
Very high	-0.05	0.11	0.13	0.00	0.11
High	-0.32	-0.20	-1.32	-1.56	-2.98
Medium	-0.49	-0.16	-1.68	-2.13	-3.97
Low	-0.23	-0.43	-1.58	-1.56	-3.20
Very Low	-0.11	-0.21	-0.77	-0.75	-1.55

I was not surprised to see that the risk of nuclear war practically disappears when all states that are capable of producing nuclear munitions hand over their arsenal to an institution, even if they still retain a “High Probability” of reacquisition. However, it is worth capturing the nuance in this variation – allowing an institution the right to Use or Retaliate lowers the risk of nuclear war only slightly. However, giving up the ability to Acquire munitions altogether drastically lowers the risk.

Chapter IX

Security Risk in State Ownership versus Institutional Ownership

Graham Allison (2000) notes that the "one real, irreducible strategic danger in the post-Cold War world that continues to be widely ignored: Russia's nuclear arsenal" in the form of "loose nukes" (website, 2000). The Council on Foreign Relations (CFR) defines loose nukes as "nuclear materials, or know-how that could fall into the wrong hands" (website, 2006). The CFR further contends that the risk is not merely from Russia but also other countries that returned their nuclear weapons but continue to maintain "stockpiles of weapons-grade uranium and plutonium" (notably Ukraine, Belarus, and Kazakhstan), countries that have nuclear plants whose radioactive by-products could be used to make a dirty bomb, as well Pakistan, which proximity to Islamic militancy and questionably security (website, 2006).

In addition to the threat of use and retaliation, I also compared the potential risk of "loose nukes" in a state-owned model versus an institution-owned model. In order to better understand the risks in a each model, I first established three baseline points for my analysis:

1. Number of nuclear warheads per country: While there are several countries that could supply either fissile or other materials for a dirty bomb, I limited my analysis to those countries that are known to have nuclear warheads. In the case of estimates that were ranges, I chose the upper end of the range.

2. Composite index score of Political Stability, Government Effectiveness, Control of Corruption, and Rule of Law: Similar to my earlier analysis, I calculated the composite score per country. My assumption is that the composite score will serve as a proxy for risk, i.e., a more stable country with less corruption, more rule of law, and a more effective government is less likely to lose its nuclear munitions.
3. Risk of conflict: The World Bank Governance Indicators (2016) and *The Global Economy* (2016) developed a War Risk index on a scale of 1 to 7 (low to high) for 2014. Furthermore, the Global Conflict Risk Index (2015) also provides a variety of indices on key metrics from 2016. Rather than dive into deeper degrees of fidelity, I used these two indices broadly to establish High, Medium, and Low categories of risk among the countries hosting nuclear warheads. My assumption is that those countries hosting nuclear warheads would be at risk of losing them during conflict due to security concerns as well as stress on military and security forces.[1]

In order to better understand the problem, I overlaid the number of nuclear warheads with the risk of conflict and the composite scores. My assumption was that it might serve as a useful visual aid to identify any obvious nuances. Figure 5 below depicts this information. Italy, Netherlands, Belgium, Germany, and Turkey are not nuclear capable; however, they have NATO bases that house nuclear warheads.

[1] The only point of contradiction between the two sources was Turkey, which the War Risk Index (2014) established as low risk of conflict while the updated Global Conflict Risk Index (2015) established as moderate risk of conflict, given current political climate. As such, I ranked Turkey at moderate risk for conflict.

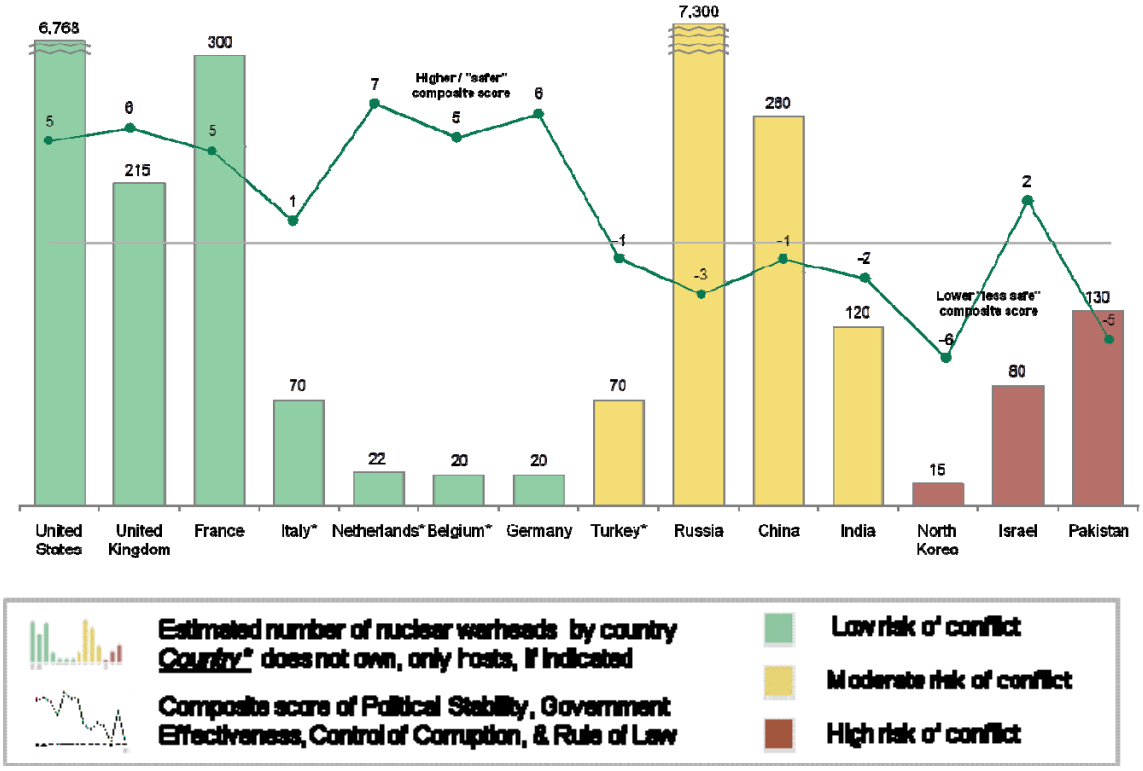

Fig. 5. Number of nuclear warheads in each country overlaid with Risk of War index and composite score of Political Stability, Government Effectiveness, Control of Corruption, and Rule of Law .

Sources: ICANW (2016), Bulletin of Atomic Scientists (2011), Global Conflict Risk Index (2015),War Risk Index (2016), World Bank (2016), and Global Economy (2016) .

Looking at Figure 5, some possible conclusions emerge:

- If it is assumed that conflict could increase the risk of losing nuclear munitions, then any institution that can either reduce or eliminate nuclear warheads in countries with moderate or high risk of conflict would reduce the risk of loose nukes.

- With the exception of Israel, there is a correlation between risk of conflict and composite score.
- As a related corollary to baseline point (1) (p. 77) above, any institutional model that can reduce the number of nuclear munitions from countries with lower political stability, less effective governments, poor rule of law, and high corruption may help reduce the risk of loose nukes.
- Ignoring geopolitical strategies, it might be useful to create an incentive for moving nuclear munitions from countries that are below the horizontal line in Figure 5 or are yellow or red, into countries that are above the line or are green. If it is assumed that the risk of conflict and the composite indices are proxies for risk of losing munitions, and if reducing the number of munitions is not a possibility, then moving the munitions into safer countries is an alternative.

With that in mind, I performed a similar probabilistic analysis of acquisition and potential of losing. Like my Acquire and Use scenario, I assumed that the composite is inversely related to the probability of losing nuclear munitions (i.e., less-rational states are more likely to lose nuclear munitions and more-rational states are less likely to lose them). I also limited the number of countries in my Very High acquisition category to just the 14 countries that are assumed to have nuclear warheads on their soil (United States, Russia, United Kingdom, France, China, India, Pakistan, Israel, Turkey, Netherlands, Belgium, Germany, Italy, and North Korea). Other countries with a high enough Jo-Gartzke index or latency were moved into the High probability category for acquisition. Those analyses produced the information in Tables

Table 33. Probability of Acquisition of states, distribution % limited just to 14 countries that are assumed to have nuclear warheads on their soil.

	P (Acquire)- Distribution % with nuclear scores and number of states						
	Very high	High	Medium	Low	Very low	Trivial	Total
%	7%	21%	12%	8%	31%	22%	100%
N	14	39	22	16	58	41	190

Table 34. Probability of Losing nuclear munitions, distribution % and number of states based on composite index.

	P (Lose)- Distribution % and number of states based on composite index						
	Very high	High	Medium	Low	Very low	Trivial	Total
%	4%	27%	41%	19%	9%	0%	100%
N	8	51	78	36	17	0	190

In terms of Acquisition and Loss, the following probabilities and number of states can be seen in Table 35(a) and (b).

Table 35(a). Percentage of states likely to Acquire and Lose in a state-owned scenario

	P (Acquire) %				
P (Lose) %	Very high	High	Medium	Low	Very low
Very high	0.29%	0.82%	0.46%	0.34%	1.22%
High	1.99%	5.54%	3.13%	2.27%	8.24%
Medium	3.02%	8.42%	4.75%	3.45%	12.52%
Low	1.40%	3.90%	2.20%	1.60%	5.80%
Very Low	0.66%	1.85%	1.04%	0.76%	2.75%

Table 35(b). Number of states likely to Acquire and Lose in a state-owned scenario

	P (Acquire) N				
P (Lose) N	Very high	High	Medium	Low	Very low
Very high	0.56	1.56	0.88	0.64	2.32
High	3.78	10.53	5.94	4.32	15.66
Medium	5.74	15.99	9.02	6.56	23.78
Low	2.66	7.41	4.18	3.04	11.02
Very Low	1.26	3.51	1.98	1.44	5.22

The next logical question is: how would a similar analysis look in an institution-owned scenario? While there could be multiple institution-owned scenarios, I opted for two: (1) where the institution owned all the nuclear munitions, and (2) the institution was located in one of the "safe" countries.

Table 36(a). Percentage of states likely to Acquire and Lose in an institution-owned scenario, where the nuclear munitions are located in states with "lower" composite scores.

	P (Acquire) N				
P (Lose) N	Very high	High	Medium	Low	Very low
Very high	0.00%	0.00%	0.00%	0.00%	0.00%
High	1.99%	5.54%	3.13%	2.27%	8.24%
Medium	3.02%	8.42%	4.75%	3.45%	12.52%
Low	1.40%	3.90%	2.20%	1.60%	5.80%
Very Low	0.96%	2.67%	1.51%	1.09%	3.97%

Table 36(b). Number of states likely to Acquire and Lose in an institution-owned scenario, where the nuclear munitions are located in states with "lower" composite scores

	P (Acquire) N				
P (Lose) N	Very high	High	Medium	Low	Very low
Very high	0.00	0.00	0.00	0.00	0.00
High	3.78	10.53	5.94	4.32	15.66
Medium	5.74	15.99	9.02	6.56	23.78
Low	2.66	7.41	4.18	3.04	11.02
Very Low	1.82	5.07	2.86	2.08	7.54

As I expected, the “high risk” element disappears entirely, and the risk of loss is shifted to more “stable” countries. If I were to add a “likelihood of loss” on top of this, based on my composite index as a proxy (i.e., more stable countries are less likely to lose), my case strengthens.

Chapter X

Deterrence Through Attribution

In her paper, "Deterring a Nuclear 9/11," Caitlin Talmadge (2007) distinguishes nuclear terrorism from other forms of terrorism "because states have to be involved at some stage in the decision chain leading to this type of attack" (p. 21). She uses the actions of Pakistan's A. Q. Khan as an illustrative example. Traditional deterrence theory works on the principle of using credible threats to dissuade parties from taking certain actions (Talmadge, 2007, p. 22; Schelling, 1960, p. 9). For deterrence to be effective, it is not just the ability to inflict damage but also the intent to inflict damage, either through punishment or denial (Talmadge, 2007, p. 22; Snyder, 1961). The Cold War focused primarily on this, with the United States and the Soviet Union trying to deter the other party through mutually assured destruction (either on each other's territories or territories of influence).

However, such a threat becomes quite difficult with non-state actors, such as terrorist groups not associated with a nation-state, where retaliation and deterrence through punishment are hard to enforce given that they typically are not localized. The only silver lining in this scenario is that nuclear munitions are extremely hard for non-state actors to create. Talmadge (2007) notes that creating fissile materials, either plutonium or enriched uranium, requires advanced technology, and infrastructure such as reactors and processing and enrichment facilities (pp. 24, 26, 27). This also is not possible without a competent labor pool with the right technical knowledge and skills

(Talmadge, 2007). Talmadge cites the example of Aum Shinrikyo,[2] which failed to create its own fissile material and was unable to succeed in buying it from Russia (p. 24).

However, while state actors maybe the only ones currently capable of producing nuclear weapons, the identification and enforcement of non-proliferation among state actors remains a problem. Albright and Hinderstein (2005) give the example of A. Q. Khan, the father of Pakistan's nuclear program, remains the most prominent example of furthering a proliferation regime. In addition to providing the means to produce fissile material (enriched uranium), Khan and his associates also provided detailed designs and instructions for the fabrication and construction of nuclear weapons based on information Khan had gathered in China. However, the construction of the materials, such as certain types of centrifuges, required a sophisticated network of "technical experts, companies, suppliers, and workshops" (p. 31). In the example of Libya, this network was extensive and spread through parts of Africa, Asia, and Europe, diversifying manufacturing and design across multiple geographies. However, Albright and Hinderstein note that such proliferation would not have happened "without the utter corruption and dishonesty of successive Pakistani governments" (p. 119), and that "Khan was motivated by money, pan-Islamism, and hostility to Western controls" (p. 117).

While controls are in place from countries who are members of the Nuclear Suppliers Group (NSG), enforcement of these controls by the members, as well as risks posed by other countries that are not NSG members (e.g., Malaysia) leave much to be desired (Albright & Hinderstein, 2005, p. 120). Similar concerns also exist with regard to

[2] Aum Shinrikyo is a Japanese doomsday cult founded in 1984. It gained international notoriety when it carried out a deadly Tokyo subway sarin gas attack in 1995 and another smaller sarin attack the previous year. Source: <https://en.wikipedia.org/wiki/Aum_Shinrikyo>. Accessed January 14, 2017.

"export control systems" in many trade zones, such as Dubai's international free trade zone (Albright & Hinderstein, 2005, p. 120).

At the 2004 and 2005 NSG Plenary meeting in Göteborg, Sweden, and Oslo, Norway, respectively, member-states agreed to improve information exchange, enforce better controls, and enable closer collaboration between NSG and the International Atomic Energy Agency (IAEA) (Nuclear Suppliers Group website, 2016):

> The 2004 NSG Plenary (Göteborg) decided to adopt a "catch-all" mechanism in the NSG Guidelines, to provide a national legal basis to control the export of nuclear related items that are not on the control lists, when such items are or may be intended for use. The 2005 NSG Plenary (Oslo) adopted a decision that supplier and recipient states should elaborate appropriate measures to invoke fall-back safeguards if the IAEA can no longer undertake its Safeguards mandate in a recipient state.

Subsequent NSG Plenaries also agreed to improve civil cooperation with IAEA (2008, Vienna), perform rigorous technical review of trigger and dual-use lists (2010, Christchurch), strengthen guidelines on enrichment and reprocessing (2011, Noordwijk), and "reference recognized IAEA recommendations for physical protection" of fuel, fissile materials, and technologies (2013, Prague) (Nuclear Suppliers Group, 2016).

In addition to these mandates from NSG and export controls, other initiatives have been created, such as the U.S. Department of State's Global Initiative to Combat Nuclear Terrorism and oversight from the Proliferation Security Initiative (PSI), created in 2003, which the U.S. Department of State defines as the following:

> The Proliferation Security Initiative is a global effort that aims to stop trafficking of weapons of mass destruction, their delivery systems, and related materials to and from states and non-state actors of proliferation concern. ((U.S. Department of State, Proliferation Security Initiative website, 2016)

As of late 2016, 105 countries have endorsed PSI, and 21 nations form the Operations Expert Group to help expedite the identification and containment of proliferation through

both legal and other means (U.S. Department of State, Proliferation Security Initiative website, 2016).

One of the goals of these initiatives is to perform forensics on nuclear materials. Naturally occurring uranium refined from its ore pitchblende only contains 0.7% U-235. For it to become fissile, it needs to be enriched to 20% U-235; for it to become weapons grade, it needs to be enriched to above 90% U-235 (CSIS, 2016). Similarly, plutonium is mostly Pu-240, with less than 0.8% Pu-239. But for it to become fissile, it cannot contain more than 18% Pu-240; for it to be weapons grade, it needs to contain not more than 7% Pu-240 (U.S. DoE, 1997). There are various ways to refine, enrich, and process fissile materials (e.g., breeder reactors), and most nation-states also choose to add trace amounts of other elements to help track the fuel and the fissile materials:

> [E]very weapon has signatures – physical, chemical, elemental – and isotopic properties that reveal something about what the weapon contained and how it was made. For example, physical signatures would depend on the nuclear material's texture, size, and shape, while chemical signatures would come from its unique molecular components . . . . ((Talmadge, 2007, p. 85)

Over time, the methods used to generate nuclear fuel and fissile materials as well as the design of nuclear weapons have become much more efficient. As a result, the weapons designs as well as the enrichment and reprocessing approaches have seen significant changes, which help to date and identify the origin of a particular weapon's design. Furthermore, fissile materials tend to have a half-life as well as trace chemical signatures, which help estimate the age and origin of the fuel. The United States' Nuclear Emergency Search Team uses this information to track the types of fuels used and the various nuclear weapons designs, as well as potential signatures left behind by the fallout and debris of various nuclear weapons (Talmadge, 2007, p. 26). Another organization,

similar to the NSG and IAEA mandates, is the Nuclear Forensics International Technical Working Group (NF-ITWG), which was formed in 1995 to help in both the pre- and post-detonation forensic analysis of nuclear material through techniques such as alpha spectrometry (detection of decaying alpha particles), evidence collection in a radiological or nuclear crime scene, high-resolution gamma spectrometry (detection of decaying gamma particles), powder X-ray diffraction, secondary ion-mass spectrometry, thermal ionization mass spectrometry, age dating, and characteristic signatures of uranium pellets (NF-ITWG, 2016). However, Talmadge (2007) and others note that the United States appears to be pursuing a unilateral approach in keeping track of forensic signatures. While sharing may expose the extent of the United States' knowledge to those with nefarious intent, it may also be helpful to build this knowledge by collaborating with a few trusted peers—including the institution being proposed herein. It is worth noting, however, that forensics in and of itself is not sufficient. Many experts believe that attribution is an imperfect science, and misinformation could be just as damaging in a different way. For instance, terrorists or nation-states could intentionally choose materials and designs that point fingers at the wrong culprit, or the signatures left behind could be unintentionally attributed to the wrong culprit.

Michael Levi (2008) discusses the need to distinguish between post- and pre-detonation retaliations (p. 20). Levi specifically cites North Korea as an example, but also extends his arguments to Russia and Pakistan, where the threat of harsh retaliation removes incentives for states to cooperate in the eventuality that they lose control over their nuclear munitions (2008, p. 21). Thus, it is worth pursuing other avenues, such as diplomatic solutions based on bargaining power as well as pre-emptive force.

Understanding Non-Proliferation Deals

Can proliferation and conflict be avoided through diplomatic means? What are the costs of and incentives for negotiating deals versus proliferation? Bas and Coe (2016) explore this in their working paper, " Give Peace a (Second) Chance: A Theory of Nonproliferation Deals." The authors note that when nation-states come to the negotiation table, their true intent needs to be identified. Ultimately, the "proliferant" has more bargaining power when it has nuclear weapons, and even the act of bargaining could be an attempt to negotiate for time to improve the proliferant's bargaining position. Using the U.S. as the "other" (henceforth called a negotiator), Bas and Coe believe that negotiations for nonproliferation are most viable at two distinct points in time. The first is at its nascent stage, where the threat of pre-emptive attack or the consequences of reneging on a deal are minimal for the proliferant. The second is when the nation-state is close to succeeding and the threat of attack from a negotiator is much more credible (Bas & Coe, 2016, p. 3). The authors argue that the uncertainty and lack of visibility into a nation-state's program in between these two points in time makes it less viable for negotiations.

Bas and Coe also note that the spectrum of possible actions depends on the relationship between the negotiator and the proliferant, as well as the potential cost and benefit to both parties. For instance, if the negotiator is unable to suitably monitor the progress of the proliferant's capabilities, then there is nothing to stop the proliferant from actively pursuing a larger and faster program. While the test serves as a mile marker for acquisitions, proliferants may have acquired nuclear capability well before their test, and their incentive is to make this known to their enemies (Bas & Coe, 2016, p. 9). Ultimately, proliferation plays a role in how the negotiator reacts, where adverse effects

on balance of power, lower costs, and increased sophistication of the proliferant's program could expedite conflict, while arms control and lowering the total cost of conflict may give incentive to deal making. (Bas & Coe, 2016, pp. 12, 30)

In their companion paper, Bas and Coe (forthcoming, pp. 27-28) also note that while lower costs maybe an objective in times of peace, the costs of a pre-emptive or preventative attack (such as retaliation, escalation, unprovoked attack, or sanctions and condemnation) would be lower in times of war. Therefore, while the model in this thesis assumes similar probabilities for both Use and Retaliation, it is worth noting that in times of war, pre-emptive strikes to prevent proliferation could increase the odds of nuclear retaliation. Such odds can only be assessed on a case-by-case basis.

Chapter XI

The World Today

At the time of writing this thesis (2016), Donald J. Trump had just been elected the 45th President of the United States. Given his pro-Russian statements and his disparaging comments regarding NATO's obsolescence ("Donald Trump Interview," 2016), there have been concerns about what this means for European security, specifically in terms of an atomic shield against the possibility of Russian aggression (von Hammerstein, et al., 2016; Kuhn, 2016). Trump's comments were not limited solely to Europe; he also questioned why the United States was shielding Japan and South Korea, and suggested that they should develop their own nuclear capabilities ("Donald Trump Interview," 2016). Such statements, combined with recent Russian actions in Eastern Europe and Russia's efforts to modernize its nuclear arsenal, understandably trigger further questions about the possibility or viability of Europe building its own nuclear deterrence against Russia.

Von Hammerstein, et al. (2016) specifically call into question the future the "trans-Atlantic security architecture" if European states are not convinced of Washington's commitment to defend Europe. If the future of NATO and its ability to act is perceived as questionable, European nation-states may believe they need to build their own deterrent. Britain and France could potentially offer such deterrence, but the exit of Britain from the European Union puts the onus of European defense entirely on France. Historically, France has not been in favor of such a responsibility, specifically stating that

extending France's nuclear shield would put France at risk of "lethal threat" (von Hammerstein, et al., 2016). This has led to the question of Germany building its own nuclear munitions capabilities, a hitherto unfathomable scenario. In November 2016, Germany's leading conservative publication, *Frankfurter Allgemeine Zeitung*, carried an op-ed by journalist Berthold Kohler (2016), who argued that Germany needed a nuclear shield if it were to bargain with Russia without depending on the United States. Soon thereafter, Roderich Kiesewetter, a senior German lawmaker and foreign policy spokesman for the conservatives in the Bundestag, and a respected leader of Chancellor Angela Merkel's Christian Democratic Union, remarked: "If the United States no longer wants to provide this [nuclear] guarantee, Europe still needs nuclear protection for deterrent purposes" (quoted in Kuhn, 2016). Kuhn himself argues that while there are potential hurdles in re-arming Germany, it is nevertheless a realistic scenario in the current political climate. While he tempers his argument by citing the general German view that is opposed to nuclear armaments, he also cautions that even the appearance of such statements represents a change in perspective from fringe to mainstream, and that "external shocks" could quickly influence policy. As an example, the South Korean view changed drastically following the third nuclear test conducted by North Korea in 2013. Dalton and Jin (2013) noted that while "elite opinion until now has largely discounted nuclear weapons . . . the North's February test broke the taboo and brought the nuclear issue into mainstream political discourse" (website, paras. 3, 4). Thus, Trump's statement and possible Russian actions could quickly jeopardize Europe's confidence in NATO's assurances.

These statements remind us that NATO, as an institution, prevented proliferation through a security alliance that was implicitly backed by the United States. It is possible

to imagine a scenario in which Europe chooses to build its own nuclear shield, thereby increasing the number of states with nuclear munitions, and subsequently raising the probabilities of use and retaliation of nuclear weapons. Now may be the time for an institution of member-states whose purpose is to shield the world from a nuclear catastrophe.

Chapter XII

A Proposed Institutional Model

Robert Dahl (1985) questioned whether democratic institutions are able to cope with and address complex issues of public policy, and whether decisions around nuclear weapons (including their design, use, and disposal) should be turned over to public stewards who have "guardianship" of these dangerous tools. In my analysis, I established that institutions can help reduce the risk of nuclear conflict, even if marginally, under the right circumstances. While that helps to answer the "why" of institutional ownership of nuclear weapons, I still need to identify the characteristics of such a successful institution.

Who Will Comprise the Institution?

For the institution to be successful, nation-states with nuclear munitions must willingly surrender control of their nuclear armaments to the institution. If there is a scenario where the majority of nation-states do not surrender control, then there is a risk of the institution will contribute to proliferation by being yet another entity armed with nuclear weapons, as I noted in my first institutional model. Furthermore, if there is a lack of trust in the institutional model, then individual nation-states may also be forced to look at alternatives to protect themselves (e.g., contemporary Germany).

What Will Be the Institutional Charter?

As I observed in my analysis, the probabilities of use and retaliation are lowest when the institution is the only owner of all nuclear munitions, and when the institution is as rational and as stable as its most rational and stable member-state, with only the institution being nuclear-capable. Furthermore, the outcome will only improve as the member-states agree to not pursue the acquisition of further nuclear munitions. Therefore, the institution must be a fluid entity, willing to eventually grow into owning all of the world's nuclear armaments. However, Bas and Coe (2016) note that the existence of nuclear capability may be a more important factor than the quantity. In fact, the institution must also work to minimize the amount of nuclear armaments in the world, with the goal of limiting "loose nukes" or the possibility of acquisition by any member in order to improve the odds of safety.

Therefore, the institution's charter should cover five key points:

- ownership and management of the nuclear munitions of its member states
- migration of current nuclear munitions to "safer" countries
- nuclear deterrence against non-member states on behalf of the institution's member states
- vertical reduction of nuclear munitions under its aegis, with a view to minimizing the odds of "loose nukes" or any other proliferation scenarios
- horizontal non-proliferation to minimize chances of use or retaliation.

What is Required for the Institution to Be Successful?

Several factors must be present if the institution is to be successful. Included are the following:

- Institutional legitimacy, where the institution is recognized in its own right and not as the extension of any one or group of nations (e.g., the U.S. is perceived by some as inappropriately influencing the United Nations).
- Multilateral due process within the institution, demonstrating that the institution is not a puppet of any one nation, and that decisions regarding the use of nuclear weapons will be made through multilateral consensus versus unilateral directives.
- Expediency in action for the multilateral due process. Due process, while effective at ensuring accountability, takes time. Retaliation and second strike will be time-sensitive, and retaliation may need to happen quickly for deterrence to be effective. Larger institutions often take time to act on decisions. Therefore, formally pre-approved measures for expedient retaliation and second-strike capabilities will help alleviate concerns of institutional lethargy. This could take the form of published formal escalation measures with signatories as a prerequisite for institutional commitment. Such escalation measures, including MAD (mutual assured destruction), may also help with crisis bargaining and helping to mitigate attack scenarios (Powell, 1987).
- Consistency of action, with no double standards, because inconsistent and unpredictable behavior will result in the institution being seen as a apologist of its powerful members, which affects institutional credibility.
- Moral authority to potentially use nuclear weapons if needed, in order for deterrence to be effective. Such moral authority would need to be derived from all member-states, with due legal and legislative approvals, for the deterrence and legitimacy to be effective. However, such moral authority should not include pre-

emptive actions, as it has been shown that pre-emption may serve to exacerbate that which it seeks to prevent.

- Authority for assurances made with the institution to be legally binding, to provide accountability.
- Legal authority to move nuclear weapons to the foreign soil of member-states to ensure safekeeping and minimize "loose nuke" scenarios.
- Ensure that the structure of the institution lends itself well to stability and rationality (e.g., all member-states will need to vote for a nuclear strike; no first strike, etc.)
- Minimize the use of treaty duration; instead, use other triggers (e.g., as long as a nation does not re-start nuclear munitions development, the treaty remains valid).
- Positive guarantees at first and, while initially difficult to implement, subsequently move on to provide negative assurances (that may potentially affect the credibility of threats).

How Will the Institution Work?

In order for deterrence to be affective, the ability to demonstrate both intent and interest on the use of nuclear weapons must be present. Other key factors are:

- an ability to influence deal-making, both pre- and post-detonation
- the ability to deter proliferation by offering an aegis of protection, legally binding, through security alliances (e.g., NATO, but with more legal support)
- the legal structure and framework to escalate issues across various agencies and world governments that are monitoring nuclear proliferation and conflict

- technical expertise from various agencies and institutions around the world, such as NSG, ITWG, IAEA, etc., to centrally coordinate threats and proliferation
- the ability to enforce non-proliferation outside of the institution on all its member-states
- planned migration of nuclear munitions into safer and more stable countries.

An Illustrative Institutional Charter

There is an old adage that says, "If you build it, they will come." While the phrase is often used in reference to bridges, it may be helpful to see an institution as the bridge between a nuclear weapons-capable and a nuclear weapons-free world. To this end, below is a proposed outline for the charter of such an institution ("The Institute"). It draws inspiration from the United Nations, and hopes to help usher in a more stable and peaceful world.

Purpose of The Institute

The Institute will own and manage the nuclear munitions of its member states, including the materiel, fissile material, and associated physical and intellectual property. Member countries agree to hand over control of their nuclear property to The Institute upon becoming a member.

The materiel, fissile material, resources, and personnel may be located in one of the member states, but all property pertaining to nuclear munitions will belong to The Institute and will be managed accordingly. It is the mandate of The Institute to determine what such "management" entails, including, but not limited to, location of munitions,

safety and security, maintenance and upkeep, change in munitions' quantities, research and development, upgrades, and disposal.

The Institute will act on behalf of its member-states to deter other nation-states from using nuclear munitions. Such actions may include The Institute itself using nuclear munitions. Members of The Institute will determine how, why, and when such actions would take place.

The objective of The Institute is to decrease the number of nuclear munitions in the world as a whole. Therefore, The Institute will work on consolidating and decreasing the total available arsenal at its disposal. While it will continue to maintain a modern arsenal to protect its member-states and to offer deterrence, it will do so in a way that minimizes threats to its current arsenal from threat, sabotage, and other risks that could further proliferation.

Regarding proliferation, The Institute will work with non-member states and world governments to increase the number of members that have nuclear munitions capability. The objective of The Institute is ultimately to become the singular owner of all nuclear munitions in the world, and address nuclear munitions issues via non-nuclear platforms.

The Institute will clearly signal both institutional motives as well as its escalation procedures, with the aim of providing full transparency to member-states as well as enemies of member-states. In order to best act on the interests of its member-states, The Institute will formalize measures to act expediently if necessary.

Guiding Principles of The Institute

- The Institute is based on the principle of sovereign equality for all its member states, and no one member-state has additional say in the due process than any other state.
- All member-states agree to not use nuclear force against another member-state as a precondition to joining The Institute.
- All member-states agree to coordinate with The Institute in the operational management of nuclear munitions, tracking of and addressing nuclear proliferation, and addressing conflicts that could result in the use of nuclear munitions.
- All member-states will coordinate through The Institute to work with both government and non-government agencies on all topics pertaining to nuclear munitions, including, but not limited to, management of nuclear munitions, proliferation, and terrorism.
- All member states agree to *confidentially* provide The Institute with information on the characteristics of nuclear munitions that were, are, or could be in their possession, such as chemical signatures of fissile materials, uniquely identifiable characteristics of enrichment processes, and weapons designs, etc.
- All states who are members agree to fulfill the obligations of belonging to The Institute, which includes curtailing further independent development of nuclear munitions, supporting vertical and horizontal non-proliferation, and working to find peaceful and non-nuclear resolutions to conflicts.
- All member-states agree that the agreements and assurances made to and by The Institute are legally binding, and these include both positive and negative assurances.

- All member-states grant to The Institute the pragmatic, moral, and legal authority to act on behalf of their best interests while remaining true to its values and long-term objectives.

Chapter XIII

Improvements to the Model

In my model, I considered the probabilities of use, acquisition, and retaliation at an aggregate level. I divided the high-probability countries in these categories into further tiers, believing that would yield better results with higher fidelity. I also used probabilities at an aggregate level because in many instances the total number of countries varied slightly (e.g., 190 versus 191).

However, evaluating the countries in each tier on a case-by-case basis could potentially be more accurate. Furthermore, a clustered analysis of the individual capabilities of each nation-state, its alliances, and the influence of its internal and external political climate, would also identify groups of countries that could be high risk, moderate risk, and low risk for use and retaliation, even within the high-probability categories.

With regard to rationality, I used a composite index taken from four other indices (Rule of Law, Government Effectiveness, Control of Corruption, and Political Stability) as a proxy for rationality, and thereafter for use and retaliation. However, other proxies for rationality may be possible. Two such approaches are suggested below.

1. Build a much stronger composite based on other World Bank governance indicators, including regulatory quality, voice and accountability, corruption perception, political rights, civil liberties, property rights, freedom from corruption, literacy rate, globalization, political risk (short-term, long-term),

special transactions risk, transfer risk, expropriation risk, and war risk. For instance, including War Risk gives a profile of nations (shown in Figure 6), where only 3.3% of states with nuclear weapons are truly at risk of war, while 10% of states with nuclear weapons are potentially at risk of war. The remaining 86.7% are essentially stable, with low to moderate War Risk.

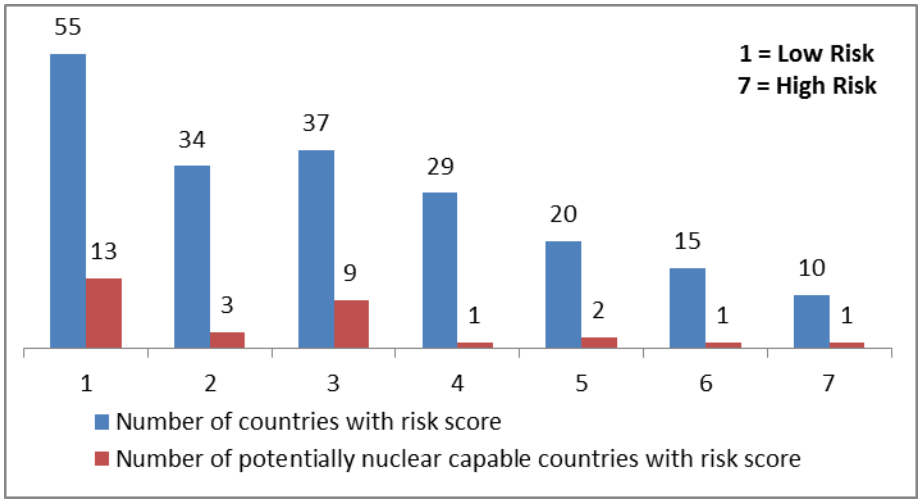

Fig. 6. Distribution of Countries with War Risk score

Source: World Bank Governance Indicators, 2016; *Global Economy*, 2016

2. Perform a case study of internal and external actions, such as elections, domestic political disputes, external conflicts, and deal making. This approach could catalog any significant actions in the past decade, and quantify their rationality for the few nuclear weapons-capable nations. The advantage of this approach is that it would be a tailored solution. The disadvantage is that it is significantly more difficult, and any cross-comparison of rationality between countries would be hard. Furthermore, a case-by-case analysis of deals for countries would be limited only to those that are in the public record.

In addition to these two proxy approaches for rationality, conducting a prisoner's dilemma analysis on an individual, case-by-case basis across the spectrum of nation-states with nuclear weapons (e.g., US vs. Iran, or China vs. Russia) and these nuances is likely to yield much more accurate results regarding the likelihood of use and retaliation, as well as potential scenarios of further interest.

Finally, as I have shown, the probabilities across the board for Use and Retaliation are quite small. This is because acquiring, using, and retaliating require the occurrence of a complex set of events. However, low-probability "black swan" events do occur, often when least expected. Regime change, political influence, and other factors could easily tip the probabilities. Factoring in such events (e.g., even a 4- or 5-sigma probability) would likely yield even more frightening results.

Furthermore, since I am calculating the probability of Retaliation as a conditional probability of Acquisition and Use, I am assuming a probability distribution similar to Use. Realistically, however, retaliation through second strike would likely happen with a probability nearing 100% in the event of a nuclear attack. Modeling such an eventuality would be simple, in that the probability of any Retaliation after Use would be 1. Therefore, in such a model, the overall objective would be to minimize the probabilities of just Acquisition and Use. However, I do not do this in my model. It is a limitation of my model that Retaliation uses the same probability distribution as Use.

Global versus Local Optimality

As I discussed in Chapter V, my model aims to optimize for global minimums, i.e., how best to reduce the overall probability of use of nuclear weapons on a global scale. However, optimal global minimums do not necessarily mean optimal local

minimums. For instance, consider the nuclear posturing in Chapter II. While institutional ownership may mitigate the acquisition and use of nuclear weapons on an aggregate level across nation-states, in fact it would put countries like Pakistan or North Korea at risk of not having a credible deterrence against conventional warfare. Indeed, it is not just the smaller countries; even Russia reversed the Soviet "No First Use" policy, citing NATO's growing conventional warfare capabilities (Lockwood, 1993).

While it could be argued that belonging to The Institute could provide some guarantees against conventional warfare, some countries may have more incentive to use nuclear weapons to prove that their threats are credible and to gain an upper hand in negotiations. Since the rate of acquisition and use of nuclear weapons is not measurable in a conventional sense, it would be difficult to perform partial derivative tests of minimums and maximums. However, the acquisition and use of nuclear weapons could be treated as discontinuous functions and bound the derivatives within the range of probabilities of acquisition (i.e., upper and lower bounds). That would allow the use of published escalation procedures to gauge discrete conditions when the upper and lower bounds maybe hit (e.g., when existence is threatened, upper-probability bound will be hit; when there is complete domestic and international peace and favorable economic conditions, lower-probability bound will be hit). This can provide a discontinuous function with partial derivatives, and help identify conditions for both local and global optimality (both absolute and relative).

Another alternative could be treating interactions between any two nation-states as zero-sum games, and identifying the Nash equilibrium.[3] Since this equilibrium would

[3] In economics and game theory, the Nash equilibrium is the stable state of a system involving the interaction of different participants, in which no participant can gain by a unilateral change of strategy if the strategies of the others remain unchanged (Wikipedia, 2017).

be the saddle point, it would help identify the relative minimums and maximums for each nation-state. However, the first caveat is that the relative maximums or minimums are not the same as the absolute maximums or minimums. But they may help identify conditions under which individual states could minimize their relative probabilities of use and acquisition relative to both the institution as well as other nation-states. The second caveat is that the use and deterrence of nuclear weapons may not be a zero-sum game, as I outlined in Chapter V. The third significant challenge is the role of imperfect information in achieving equilibrium. Michael Ummels and Dominik Wojtczak (2009) talk about the challenges of computing equilibria in multi-player stochastic games. Sam Ganzfried and Tuomas Sandholm (2009) proved that even in conditions of imperfect information, many common algorithms for solving multi-player stochastic games as well as the new algorithms they devised "can never converge to a non-equilibrium" (p. 8). They were also able to identify approaches that minimized external regret in instances of both perfect and imperfect information availability (Ganzfried & Sandholm, 2009, p. 7). This means that even in the absence of perfect equilibrium (after accounting for stochasticity *ex post facto*), other points of convergence may be found. What this means for an institutional model is that even lacking perfect information, conditions could identified where an institutional model (global minimums) could coexist with a state deterrence model (local minimums), where both optimize for minimization of nuclear use probabilities to each others' benefit.

Chapter XIV

Studium Pacis per Arma

It is my hypothesis that institutional ownership of nuclear munitions will encourage a lower probability of nuclear war in comparison to state ownership of nuclear munitions. In this thesis, I analyzed the probability of nuclear war under both scenarios, while identifying the criteria that enable an institutional ownership model to mitigate the likelihood of nuclear war compared to a state ownership model. Specifically, I found that circumstances of nuclear war are mitigated most in institution-only ownership of nuclear munitions, with the rationality of the institution being the rationality of the most rational participating nation-state, and where only the institution is nuclear-capable.

Jervis (1978) notes the dilemma of increased security, and the need to seek alternatives to strengthen security relative to other states. In this context, just building an institution is not sufficient to mitigate potential nuclear war. For an institutional model to be successful, it is imperative that it act as an institution of superior defensive deterrence, not one of threat. This nuance is vital because defensive deterrence maybe warranted; threats need not be. An institution also needs to provide assurances that superior security capability, in the form of nuclear munitions, comes with the purpose of protecting its member-states, and that such protection can be easily obtained by joining the institutional model.

I also identified the characteristics that would shape an institutional model, and the conditions that would enable an institutional model to be successful. Notably, these

include institutional legitimacy, multilateralism, transparency, consistency in action, legal and moral authority, expediency, positive guarantees and negative assurances, and a well-coordinated long-term vision that promotes non-proliferation.

I believe that the implementation of such an institutional model would serve to equalize the balance of power as well as provide a differentiated capability through nuclear deterrence and the presence of superior firepower, while minimizing the risk of nuclear war. It is my hope that this would be an incentive for most nation-states to take refuge in the security of the institutional model, and help them build a safer world.

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