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The Institutional Design of Arms Control: To What Extent Does Institutional Design Increase the Longevity of Arms Control Agreements?

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The Institutional Design of Arms Control: To what extent does institutional design increase the longevity of arms control agreements?

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Abstract

The technical institutional design of arms control agreements remains a rather unexplored area of arms control. But the increasing uncertainty of future arms control efficacy requires a re-examination of the agreements' institutional design to determine which components contribute positively to their longevity. This research examines the role of dispute settlement bodies as specific outside consultative bodies, verification regimes, membership as at least one nuclear-armed state party to the agreement, and technology transfer mechanisms in arms control agreements. It found that membership and a lack of technology transfer mechanisms are necessary to positively impact the longevity of an arms control agreement, meaning agreements are longest when at least one nuclear-armed nation is involved. Technology transfers were present in only a few agreements, but may have complicated agreements or made empty promises, impacting the duration of those agreements. Dispute settlement bodies and a lack of verification regimes are sufficient but not necessary conditions to positively impact longevity in this research. The relationship between a lack of verification regimes and longevity is the most interesting and suggests there may be an ideal level of verification.

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Introduction

As the threat of more nations acquiring and seeking nuclear technology increases, as well as the possibility of a new arms race among great power competitors, the United States must be prepared to create agreements that prevent nuclear proliferation and its consequent threat to regional and international security. Advancements in technology, including new delivery vehicles, more effective missile defense systems, and the deployment of tactical nuclear weapons have continued to challenge current arms control agreements and treaties. The need to address the destabilizing impacts of technological advancements continues to increase. To help inform future efforts to address these challenges, this research examines which institutional design components of arms control agreements contribute to their longevity.

The numerous agreements between the United States and the Soviet Union during the Cold War contributed to relative stability and transparency between these great powers. The goal of these agreements was to reinforce the doctrine of Mutually Assured Destruction (MAD), in which mutual deterrence between adversaries rests on their capacity to destroy the other no matter who strikes first. A second set of agreements, including the 1995 Bangkok Treaty, pursue the goals of non-proliferation and disarmament that were set forth in the Treaty on the 1968 Non-Proliferation of Nuclear Weapons (NPT). However, those agreements have not kept pace with the increased number of nuclear weapons states. The NPT was created in a world with only five nuclear states, while there are now nine. Although this number has not grown exponentially, the danger of new nuclear-armed states has risen in light of advancing

technology and deteriorating relationships between adversaries. The few living treaties are also expiring and being challenged by these technological advancements. These agreements are fundamental, as, without them, less transparency and the chances of escalation and misunderstanding increase the likelihood of rising tensions and war.

To create more sustainable treaties and agreements, the United States should learn from the past to inform future efforts. Even as relationships and ideologies change across U.S. administrations, arms control agreements should be maintained and created in the best way to reflect domestic and international interests. This research seeks to contribute to the prospects of enduring future U.S. arms control treaties by asking to what extent structural conditions increase the longevity of arms control agreements.

I argue that the institutional design of arms control agreements, including dispute settlement bodies, verification regimes, membership, and technology transfer mechanisms, increases the longevity of agreements. While these are not the only factors impacting the longevity of agreements, they play, I will argue, the largest role in strengthening linkages between states by taking advantage of ongoing international agreements.

This research places longevity as the outcome variable but does not argue about compliance. As Raustiala says, "Effective enforcement is an outcome that may vary on the basis of a range of other factors," which are beyond the scope of this thesis.[1] Longevity is the chosen outcome variable due to a variety of factors. States remain a party to an agreement if the agreement is considered in their best interest, regardless of

[1] Raustiala 2005.

complaints of non-compliance, proving its utility to states. Longevity does not assume full compliance but assumes states remain interested in the goal of the agreement. While compliance is often the goal of treaties, non-compliance creates a further understanding of the limitations of the agreement and produces opportunities for future efforts. Sarah Kreps demonstrates that if an agreement builds on a previous one, it has a higher chance of becoming binding.[2] Thus, the longer an agreement is in force, the higher the likelihood it can become a treaty or produce further agreements and create more institutionalized norms.[3] While longevity is not often the overarching goal of agreements, longevity can be a measure of utility.

This paper will provide further discussion on how longevity is measured under the methodology. This research also views arms control agreements with a wide lens, meaning arms control encompasses disarmament efforts as well. The dataset used in this research does not distinguish between the goals of an agreement and does not consider differing incentives for creating agreements.

This argument is advanced by examining the history of arms control agreements and analyzing the changing international security environment in the era of great power competition and technological advances. It also provides a literature review exploring previous approaches to explaining the structure of agreements and their relevance in this changing environment.

[2] Kreps 2016.

[3] This research assumes that agreements are beneficial to a nation and are in the best interest of a nation.

The second section explains the methodology used for analysis, including how each component is measured and the decision behind each. It will provide the results of the quantitative analysis, followed by a discussion of applicability. Further, it will consider the limitations of this research and provide recommendations for further study.

Section I: Nuclear Arms Control in a Changing Security Environment

This section will explore how arms control agreements have changed since the creation of the NPT and provide an overview of the current security environment. It will also explore previous literature on the structural design of agreements.

History of Nuclear Arms Control Agreements

The most widely adopted arms control effort was the creation of the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) in 1968. A total of 191 states have joined the treaty, making it the most ratified treaty regarding arms limitation and disarmament. The NPT created the current safeguards system under the International Atomic Energy Agency (IAEA) and has been the basis of future agreements.

> "The Treaty is regarded as the cornerstone of the global nuclear non-proliferation regime and an essential foundation for the pursuit of nuclear disarmament. It was designed to prevent the spread of nuclear weapons, to further the goals of nuclear disarmament and general and complete disarmament, and to promote cooperation in the peaceful uses of nuclear energy."[4]

The NPT created the current international safeguards system under the IAEA. This system allows the IAEA to conduct verification through a range of inspections, including routine inspections. The Comprehensive Safeguards Agreements (CSA) also allow IAEA inspectors to use remote monitoring and collect environmental samples in facilities. The NPT also "…promotes cooperation in the field of peaceful nuclear technology and equal access to this technology for all States parties, while safeguards

[4] Text of the NPT via the United Nations, https://www.un.org/disarmament/wmd/nuclear/npt/text

prevent the diversion of fissile material for weapons use."[5] This is notable because it encourages equal access to peaceful nuclear technology to all. As mentioned later in this research, there are few agreements with technology transfer mechanisms that explicitly transfer peaceful nuclear technology to states without it.

Since the NPT, many arms control agreements have been completed between the U.S. and Russia. In 1972, the United States and the Soviet Union, the two nations with the largest arsenals, created two new agreements. The Strategic Arms Limitation Treaty (SALT) I Interim Agreement and the Anti-Ballistic Missile (ABM) Treaty were both signed on May 26th, 1972.[6] The ABM treaty limited defensive systems to a strategically insignificant level, limiting offensive arms races by halting both sides' efforts to evade Mutual Assured Destruction, a U.S. doctrine.[7] By 1970, the United States had an estimated 26,008 warheads in its stockpile, and the Soviet Union had 11,736, making arms control a way to end the costly, futile, and dangerous arms race between the U.S. and USSR.[8] Despite the U.S. having more nuclear weapons, American leadership believed there was a missile gap in favor of the Soviets; the Soviets were increasing their technological innovation and were starting to deploy multiple independently targetable reentry vehicles (MIRV), allowing each of their missiles to have multiple warheads. The

[5] IAEA website on safeguards agreements.

[6] Atomic Archive, https://www.atomicarchive.com/resources/treaties/salt-I.html

[7] There are ongoing debates determining whether the Soviet Union accepted this concept.

[8] "Changes in Size of U.S. Nuclear Weapons Stockpile, 1945-2015 https://fas.org/wp-content/uploads/2016/05/stockpile1.jpg; "Status of World Nuclear Forces" FAS, https://fas.org/issues/nuclear-weapons/status-world-nuclear-forces/

idea that the U.S. could not attack the Soviets and "win" meant they were at a stalemate, and thus arms control would now be effective. Once a nation's capacity to win in war is diminished, then arms control becomes advantageous; this can be seen during the Cold War. The Interim SALT Agreement froze the number of strategic ballistic missiles at 1972 levels for five years. These agreements also established the verification method of using national technical means, meaning verifying compliance without requiring access to the other nation's territory, allowing for transparency between the two sides.[9]

The follow-on treaty to these agreements, Strategic Arms Limitation Treaty (SALT) II, was negotiated and signed in 1979. Although never ratified, it set ceilings on strategic offensive weapon systems and set qualitative limits on existing and future strategic systems.[10] President Carter and President Reagan supported the SALT II agreement, agreeing to show "mutual restraint" by not violating the treaty limits.

In 1987 the Intermediate-Range Nuclear Forces Treaty (INF) between the United States and Russia was signed, and it entered into force on June 1st, 1988. This was the first treaty to eliminate a category of nuclear weapons rather than set limits. Intermediate-Range missiles allowed Russia to hold European nations at risk, prompting the United States to agree to reductions that eliminated all missiles with ranges between 500 and 5,500 kilometers, their launchers, and associated support structures.[11] "At the time of its

[9] Atomic Archive, https://www.atomicarchive.com/resources/treaties/salt-I.html

[10] The United States did not ratify this bilateral agreement after the Soviet Union invaded Afghanistan in 1979. Atomic Archive, https://www.atomicarchive.com/resources/treaties/salt-I.html

[11] Atomic Archive, https://www.atomicarchive.com/resources/treaties/inf.html

signature, the Treaty's verification regime was the most detailed and stringent in the history of nuclear arms control," using national technical means, on-site inspections, and cooperative measures.[12] The INF also explicitly banned interference with photo-reconnaissance satellites, which was the basis for national technical means (NTM).[13] The INF was significant because it helped bring the end of the Cold War and signaled the reversal of 40 years of military competition between the U.S. and Russia. Unfortunately, new Russian INF deployments were followed last year by U.S. withdrawal from the INF Treaty. Coupled with Chinese INF deployments, that longstanding post-cold war success has been supplanted by a new and complex challenge to arms control negotiations.

Since the INF treaty, the United States and Russia have continued to negotiate arms control treaties focused on limiting and reducing strategic weapons. The New Strategic Arms Reduction Treaty (START) treaty, signed in 2010, "enhances U.S. national security by placing verifiable limits on all Russian deployed intercontinental-range nuclear weapons."[14] Although it was extended for another five years in 2021, it is set to expire in 2026. After New START expires, it is expected that the U.S. and Russia will have to negotiate a new treaty to handle accumulating technological advancements.

Beyond the bilateral treaties between the U.S. and Russia, the Comprehensive Test Ban Treaty (CTBT), signed in 1996, includes the United States, the United Kingdom, and 90 non-nuclear-weapon states. The CTBT would ban any and all nuclear

[12] Atomic Archive, https://www.atomicarchive.com/resources/treaties/inf.html

[13] Arms Control Association Fact Sheet, INF https://www.armscontrol.org/factsheets/INFtreaty

[14] Department of State, 2020.

tests above and below the Earth's surface. It has never been ratified by all 44 nations required for it to take effect, but it did establish a worldwide monitoring system for determining if a nuclear explosion had taken place. Similar to the CTBT, other agreements have been negotiated but do not hold legal authority over nations but have provided an avenue for follow-up discussions.

In the 21st century, the number of agreements has slowed down. The most notable agreements are the Joint Comprehensive Plan of Action (JCPOA) signed in 2015, and the Treaty on the Prohibition of Nuclear Weapons (TPNW) created in 2017. The JCPOA was a multilateral agreement between the P5+1 (United States, United Kingdom, France, Germany, China, and Russia) and Iran. The goal was to prevent Iran's nuclear program from progressing by providing economic relief in exchange for concessions and verification of their compliance. After being signed in 2015, the Trump administration removed the United States as a participant in 2018. The JCPOA is still under re-negotiation as of this writing. The TPNW is the most recent agreement, which is a "comprehensive set of prohibitions on participating in any nuclear weapon activities."[15] As of July 2021, 55 states have ratified the TPNW, with another 33 as signatories. These most recent agreements are not included in the dataset but provide context as to how agreements have changed since the 1970s.

[15] Atomic Archive, https://www.atomicarchive.com/resources/treaties/tpnw.html

The Changing International Security Environment

The first atomic bombs dropped on Japan in 1945 changed the way nations thought about war. The massive destructive power of these weapons made the costs of going to war with a nuclear-armed nation more severe than any potential benefit to be gained. This became the basis of the theory of MAD, which arguably explained why the Cold War did not lead to World War III. After the U.S. dropped the first bombs, the Soviet Union raced to build up its nuclear arsenal, creating a massive arms race that resulted in the centrality of nuclear weapons to the military strategies of both nations. Eventually, each side realized they could not win a nuclear war and adopted arms control measures.

Since the end of the Cold War, the role of nuclear weapons in American grand strategy has declined. As the Soviet Union fell and new agreements were reached, Russia and the United States greatly reduced the number of nuclear weapons. In turn, their prominent role in U.S. strategy as a first use option also diminished, turning them into a last resort option. The U.S. quickly found itself turning its attention to a new kind of war in the 21st century.

The September 11th attacks on U.S. soil shifted the focus away from Russia and towards non-state actors. This new “war on terror” became the focal point of U.S. strategy. Despite this shift away from the use of nuclear weapons against adversaries, the Bush administration was concerned about nuclear weapons and nuclear technology falling into the hands of non-state actors. This resulted in the Proliferation Security Initiative (PSI) in 2003. "PSI seeks to enhance interdiction capabilities and increase

coordination between states to disrupt trade in weapons of mass destruction (WMD), delivery systems, and related materials."[16] That same year, fear of Iraq acquiring nuclear weapons was a major reason for President Bush's decision to invade the country and replace its ruling regime. The Obama administration continued these initial efforts through the Nuclear Summit Series.

Between the end of the Cold War and the start of the Obama administration, dialogue around nuclear weapons had decreased. The Nuclear Summit Series and the New START treaty brought nuclear weapons back into public view. Obama had reaffirmed his belief in non-proliferation and eventual disarmament, giving more focus to arms control efforts. This focus created the 2010 New START agreement with Russia and the 2015 JCPOA with Iran. These agreements created more transparency regarding nuclear programs and continued verification techniques. Although the JCPOA is still going through discussions, the few years it was fully in force gave the world a closer look into Iran's nuclear program, and their progress could be verified.

Despite an increase in attention during the Obama administration, the real change in public awareness of these issues came in 2018, when President Trump's 'fire and fury' threats against North Korea, and his decision to remove the U.S. from the JCPOA,[17] revived long-dormant fears of nuclear weapons. Incentives to continue to comply with agreements remain questionable, especially after Iran had sanctions reimposed despite

[16] Davenport 2020.

[17] Pramuk 2017.

expert agreement that they had complied with the JCPOA, but history has shown the world is more stable with transparency regarding states' programs and arsenals.

In the face of technological advancements, combined with the rise of China and conflicts in the Middle East, nuclear weapons are starting to play a larger role within U.S. grand strategy, making arms control agreements increasingly important. New multi-domain actions, including within cyber and space, have changed the security environment. The U.S. now faces an information war even as the threat of Islamist terrorism has waned. Advanced technology has also started to erode deterrence through the accuracy of delivery systems and remote sensing.[18]

The increased murkiness of the "grey zone" and escalation in other domains have made the role of nuclear weapons unclear. The 2018 Nuclear Posture Review states that the United States may use nuclear weapons in response to a non-nuclear attack, blurring the nuclear threshold.[19] Cyber-attacks may also disrupt chains of command, which could make the U.S. more vulnerable to a nuclear attack or more likely to conduct an attack.

New advances in weapons have also changed the security environment. Russian reliance on offensive nuclear forces combined with more sophisticated U.S. missile defense capabilities has created a more tense relationship. The deployment of low-yield nuclear weapons has arguably lowered the threshold of nuclear war, making mistakes or miscalculations more likely. Lower-yield weapons are also seen as retaliatory or warning

[18] Lieber 2017.

[19] Department of Defense 2018.

weapons and are more accurate. These create a more credible deterrent but also diminish the credibility of a "no first-use" stance.

The rise of China and its expanding arsenal has also restarted great power competition with a focus on nuclear weapons. Despite China's supposed No First-Use policy, it is expanding its nuclear arsenal. While its current arsenal of about 250 weapons pales in comparison to the U.S. and Russia, its expansion, along with heavy investments in weapons technology, make their inclusion in arms control agreements vital to their success.

This changing security environment continues to challenge long-standing ideas of deterrence and has made arms control agreements both more challenging to design and even more necessary. Future agreements must account for low-yield weapons, increased missile defense capabilities, anti-satellite capabilities, declaratory policies, and the need to include additional actors in negotiations. However, without these agreements, the world may face a larger and more expensive arms race that brings the world closer to nuclear war.

Literature Review

The literature examining the institutional design of arms control agreements through quantitative analyses remains limited; most literature either examines whether or how institutions shape state behavior or the design of international institutions within economic or environmental cooperation. This review of previous scholarly work is not exhaustive but provides a brief overview to frame this research.

The term arms control agreements encompass different objectives. "An 'arms control agreement' is an agreement among sovereign states…that can be bilateral or

multilateral" that intend to "(a) freeze, limit, reduce or abolish certain categories of weapons; (b) ban the testing of certain weapons; (c) prevent certain military activities; (d) regulate the deployment of armed forces; (e) proscribe transfers of some militarily important items; (f) reduce the risk of accidental war; (g) constrain or prohibit the use of certain weapons or methods of war; and (h) build up confidence among states through greater openness in military matters."[20] Although some experts may distinguish between arms control and disarmament, this research considers each of these goals as within arms control generally, and therefore an arms control agreement. This broad definition was the original criteria for Krep's dataset; therefore, this research remains consistent with that conception.

At a broad level, arguments regarding the value of institutions that underpin and can lead to agreements are rooted in contending theories of international relations. Realist skeptics include John Mearsheimer, who argues that "institutions have minimal influence on state behavior, and thus hold little promise for promoting stability in the post-Cold War world," as states are driven by their own security needs.[21] Agreements can be seen as a process of institutionalizing norms and behaviors and could be a source of maintaining security advantages; the technical design of agreements contributes to this institutionalizing mechanism. The desire to prevent another nation from gaining an advantage and preventing an arms race are the main advantages of arms control seen by the realist school of thought.

[20] Goldblat 2002.

[21] Mearsheimer 1994.

Institutionalists, Robert O. Keohane and Lisa L. Martin, argue that “institutions sometimes matter, and that it is a worthy task of social science to discover how, and under what conditions, this is the case.”[22] Institutionalists see institutions as a way of creating global norms, which reinforce state behaviors and influences decisions not only in the moment, but in the future as well. "States spend significant amounts of time and effort constructing institutions precisely because they can advance or impede state goals in the international economy, the environment, and national security."[23] Keohane and Martin argue, "This necessity for institutions does not mean that they are always valuable, much less that they operate without respect to power and interests, constitute a panacea for violent conflict, or always reduce the likelihood of war."[24] Whether institutions are valuable is out of the scope of this paper, but these two views are the basis for regime theory.

Regime theory “seeks to explain the occurrence of cooperation among States by focusing on the role that regimes play in mitigating international anarchy and overcoming various collective action problems among States.”[25] Regime theory, along with game theory, were focused on the theoretical incentives for cooperation rather than the actual

[22] Keohane, 1995.

[23] Koremenos et al. 2001.

[24] Keohane 1995.

[25] Bradford, Anu. “Regime Theory.” Columbia Law School. 2007. https://scholarship.law.columbia.edu/cgi/viewcontent.cgi?article=2971&context=faculty_scholarship

design of the institutions. These approaches fall short due to this but were the basis for this field of research, ultimately resulting in rational design theory.[26]

Rational design theory, first advanced by Barbara Koremenos and extended from cooperation theory, argues that conscious design is the overriding mechanism guiding the development of international institutions. It treats "institutions as rational, negotiated responses to the problems international actors face."[27] This approach "provides an appropriate foundation for prescribing policy and evaluating existing institutions."[28] Applying rational design to arms control agreements allows us to examine the relationship between the technical structure of an agreement and different outcomes; this research specifically looks at how the technical design of an agreement relates to an agreement's duration.

Rational design argues institutional evolution is based on changes made in response to changing conditions; in this research, this idea is reflected in need for agreements to respond to technological changes discussed previously. Koremenos' original work put forth five institutional decisions that vary within designs: Membership, scope, centralization, control, and flexibility. This research draws on the variability within membership, centralization, and flexibility that rational design theory lays out. The scope is pre-determined since this research focuses on arms control agreements.

[26] Koremenos et al. 2001.

[27] Koremenos et al. 2001.

[28] Koremenos et al. 2001.

There is previous work using rational design theory examining the design of international agreements, particularly economic cooperation and environmental agreements.[29] In the national security realm, there has been limited scholarship on the technical design of arms control agreements. Sarah Kreps completed the first quantitative research in this arena, focusing on how legalization affects how arms control agreements enter into force. Her research addresses institutional designs by looking at obligation, precision, and delegation within arms control agreements.[30] Kreps also created a dataset that includes all arms control agreements proposed since 1945 and their dates of signature and entry into force (if applicable). Andrew Reddie furthered Kreps' work by researching the effect of four conditions on compliance to an arms control agreement.[31] Reddie's research examines how the type of an agreement, the types of verification regimes in terms of depth, the perpetuity of an agreement, and membership impact compliance.

This paper seeks to build on Reddie's research by examining a different set of components and their impact on longevity using rational design theory as the basis for this research. By taking a mixed-method approach, this research seeks to find patterns in the design of agreements that can be replicated. The qualitative aspect adds a discussion

[29] Aggarwal, Institutional designs for a complex world: Bargaining, linkages, and nesting; Abbott and Snidal, "Hard and soft law in international governance"; Koremenos, "Loosening the ties that bind: A learning model of agreement flexibility"; Barbara Koremenos, Charles Lipson, and Duncan Snidal, "The rational design of international institutions," International organization 55, no. 4 (2001): 761–799; Mattli and Woods, The politics of global regulation; Oran R Young, Compliance & public authority: A theory with international applications (RFF Press, 2013); Ronald B Mitchell, "Problem structure, institutional design, and the relative effectiveness of international environmental agreements," Global Environmental Politics 6, no. 3 (2006): 72–89.

[30] Kreps 2016.

[31] Reddie 2019.

to the results, allowing this research to speculate on why these relationships exist. The basis for examining each component is also found in previous literature.

The rationale for the importance of dispute settlement bodies was best stated by John McNeill, Assistant General Counsel for International Affairs and Intelligence, U.S. Department of Defense, in 1990: "Without a procedure for dealing with disputes, i.e., compliance problems, the fundamental goals of arms control -- the reduction of the risk of the outbreak of war, the enhancement of strategic stability, etc.-- depend upon the transparency and predictability of relationships, including legal arrangements. And the stability of legal relationships depends in large measure on the availability of an effective dispute resolution process."[32] Dispute settlement bodies enhance arms control agreements by creating specific avenues for discussion of issues that have arisen or may arise. They also create formalized avenues or encourage discussion before the issue rises to the level of an outside body. Raustiala's research also considers strong structures within agreements to be those "which a central body issues a specific determination about a specific party."[33] While this research does not consider strong versus weak structures, it does use Raustiala's distinction to determine whether a DSB exists in an agreement. Due to its important role, this research chose to examine dispute settlement bodies' effect on longevity to determine if these avenues increase the duration of an agreement.

Verification regimes play a similar role in reducing the risk of tensions escalating as they reinforce compliance. Goldblat discusses two distinct roles of verification: to

[32] McNeill et al. 1990.

[33] Raustiala 2005.

deter cheating and to act as a confidence-building measure. As a confidence-building measure, verification ideally "generate(s) an international belief in the viability of agreed arms control measures and to instill trust in the participating states that their national interests are protected."[34] Since this research does not examine compliance, the confidence-building role of verification regimes provide the basis for including this design component. While deterring cheating may be important, agreements have remained in force even with known cheating, therefore it could be argued the confidence-building mechanism is just as important as the ability to prove compliance.

The membership of agreements is also a key component of any agreement. Reddie discusses the "consequences of adding additional players to an arms control agreement—either related to their impact on the bargaining or enforcement related to the regime."[35] This research only examines whether at least one party was a nuclear-armed state, but previous research has broken membership down to examine the effects of multilateral, minilateral, and bilateral negotiations. This component raises questions for the future of agreements that do not contain nuclear-armed nations, including the recent TPNW.

Technology transfer mechanisms were included in this study because they represent economic gains for the participants of the agreement. The lifting of sanctions – a common tool used to bring nations to negotiations – is not a component of institutional design. Instead, built-in mechanisms that create an economic gain, such as the gain of

[34] Goldblat 2002.

[35] Reddie 2019.

knowledge, skills, and equipment, take their place in this research. This inclusion of economic gains widens the scope of an agreement; Koremenos states, "A trade issue…may be linked to a security issue to facilitate agreement and compliance. Or a side payment may be offered, as when the Nuclear Nonproliferation Treaty offered the transfer of peaceful nuclear technology to states that agreed to forgo nuclear weapons. Such side payments are clear evidence that scope is being manipulated to facilitate cooperation."[36] The inclusion of these mechanisms is another form of linkages that may facilitate compliance and cooperation, making them an interesting component to examine.

Connecting the idea of institutionalism more directly to the components of this research, Keohane states, "Institutions enhance the prospects for cooperation among states by increasing the flow of information and opportunities to negotiate; by helping monitor compliance with commitments; and by shaping expectations about the future context of commitments."[37] Dispute settlement bodies increase opportunities to negotiate while verification regimes increase the flow of information and monitor compliance. Technology transfer mechanisms could also increase opportunities for cooperation by expanding an agreement's scope. Institutions create a climate for cooperation that often underpin agreements, strengthening the resilience of agreements. This can be seen in the creation of the IAEA that now plays an integral role in numerous arms control agreements. This overview of previous literature gives a basis for how this research was

[36] Koremenos, et al. 2001.

[37] Nye 1991.

approached and conducted, including why each institutional design component was chosen.

Section 2: The Structural Components of Nuclear Arms Control Agreements

Using the previous theories of institutional design, combined with the lack of literature on the design of arms control, this research seeks to determine to what extent certain technical structural components contribute to the longevity of arms control agreements. This section will explain the methodology used, the results of the study, and then provide implications from these results. It will then discuss limitations to this research and avenues for future research.

Methodology

This research will use a Qualitative Comparative Analysis (QCA) to determine the contribution of certain conditions related to the outcome variable. This mixed-method approach will analyze four conditions (dispute settlement bodies, verification regimes, membership, and technology transfer mechanisms) in relation to the outcome variable, longevity. Although each of these independent variables may exist with different intensities in the various agreements, a presence/absence scale is used.[38]

By using a QCA, this research can determine under what conditions the outcome, long duration of an agreement, occurs. The goal of this method is to reduce the complexity of arms control agreements by focusing on the absence or presence of a few variables and examining their effect on a specific outcome variable. While this method does simplify variables at the design stage, "QCA develops a conception of causality that

[38] The condition is considered present or absent according to the requirements below and are coded with a one when present, and a zero when absent in the model.

leaves room for complexity, referred to as 'multiple conjunctural causation.'…QCA techniques can be used inductively, gaining insights from case knowledge in order to identify the key 'ingredients' to be considered"[39] The ability to account for complexity and determine which factors contribute to a specific outcome are strengths of this approach. A QCA also allows for replicability since the analysis is quantitative, which is important with only a few studies done on this topic. Different datasets could be used to examine the different outcomes, and the coding of each agreement could be debated, allowing for variation within QCAs.

This method also has its own limitations. By taking a quantitative lens to the design components, this research does not account for political winds or technological advancements that may impact the duration of agreements. It assumes these intervening aspects occur before the agreement is created and is reflected in the structure itself, however, it does not take account of these variables. These are two key aspects that are not accounted for in this method but may have an important impact on the duration of an agreement.

As mentioned before, arms control agreements are broadly defined in this research. They are not specified by their goals or whether they are bilateral or multilateral. To remain replicable, this research uses Sarah Krep's dataset of 48 agreements, which is based on this broad definition.[40] Of those cases, 29 meet the

[39] Berg-Schlosser et al. 2008.

[40] Kreps 2016.

condition of having entered into force.[41] Each case is coded by the year it entered into force (EIF), the year the agreement was terminated, the total number of years in the force, and whether each condition is present or absent. An example table is presented below. The full table of cases included in this study is in the appendix.

Dispute settlement bodies (DSB) are defined as a formal, specific process or an outside body to resolve issues between parties. A formal, specific process includes steps that result in the issue being referred to an outside body, such as the United Nations Security Council or the International Criminal Court. DSBs are also considered outside bodies within the agreement, such as the Standing Consultative Commission in the ABM Treaty that was tasked with "consider[ing] questions concerning compliance with the obligations assumed and related situations which may be considered ambiguous." Dispute settlement bodies will be characterized as present or absent; a present condition is coded with the number one, while an absent condition is coded with the number zero in the quantitative analysis.

Verification regimes are defined as having specified avenues for all parties to verify the necessary information in relation to the treaty, including but not limited to national technical means, on-site inspections, and "portal monitoring."[42] Each of these is not mutually exclusive and is often used in tandem. To be considered a verification regime, there must be at least one of these verification methods explicitly stated in the

[41] It would be impossible to properly gauge the longevity of an agreement that did not enter into force.

[42] Reddie 2019.

agreement. Verification regimes will be characterized as present or absent for this analysis.

Membership is defined as signatories to an agreement. The key distinction for membership will be whether the party is a nuclear-weapon state or a non-nuclear-weapon state. Due to the binary nature of this analysis, membership is positive and considered present when at least one nuclear-weapon state was a signatory to the agreement or treaty.

Technology transfer mechanisms are designated or explicitly stated means to facilitate the movement of technology, consisting of knowledge, skills, and equipment.[43] These can include but are not limited to licensing agreements, memorandums of understanding, and explicit transfer of technology. These are coded as present or not in agreements. In the Hotline Treaty, the United States provided communication equipment to the Soviet Union that was explicitly stated in the agreement, rendering it a technology transfer mechanism. The Trilateral Statement in 1994 transferred funds from the Soviets to Ukraine for their enriched uranium. In agreements not covered in this research, such as the Agreed Framework between the U.S. and North Korea, the U.S. was "to facilitate the construction of two 1,000-megawatt light-water nuclear power reactors." While the Hotline technology transfer was aimed to create more communication and de-escalate scenarios, the Trilateral Statement, and Agreed Framework transfers were aimed at non-proliferation. This component is also coded as present or absent.

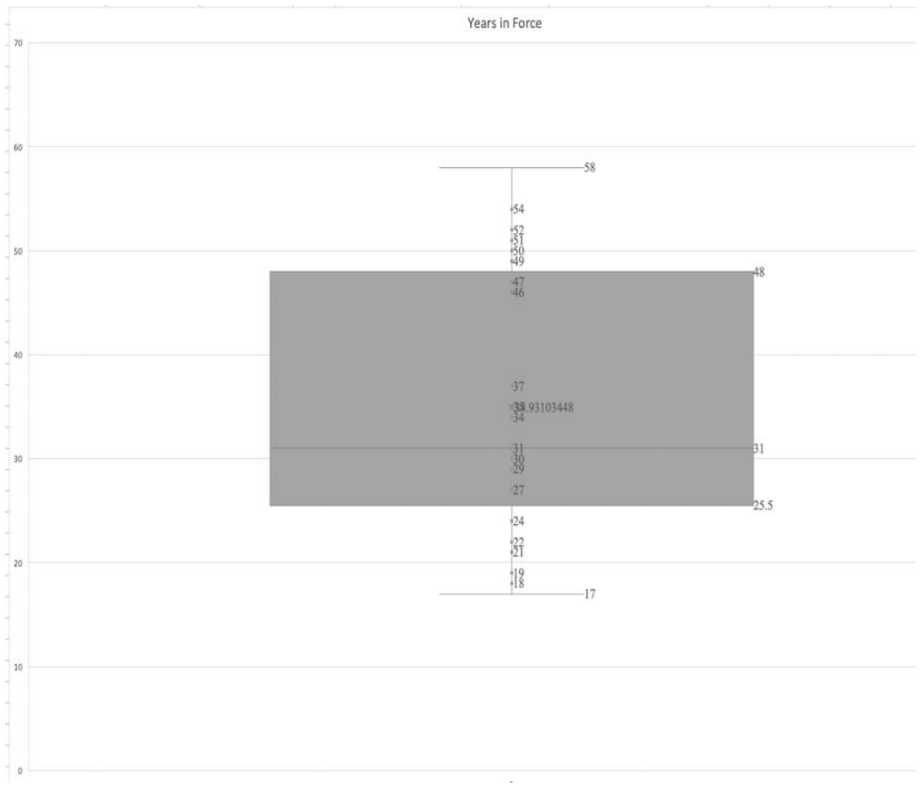
[43] Combining definitions from different sources, including Andre Buys (Grange, L.I. & Buys, Andre. (2012). A review of technology transfer mechanisms. The South African Journal of Industrial Engineering. 13. 10.7166/13-1-320.)

Longevity is the length of an agreement from the time it was signed to the time it expired or was no longer in force. To maintain the binary system, agreements will be considered “long” if they lasted greater than 24 years.[44] Agreements that were in force or respected for 24 years or less will be considered “short.” The decision for this duration range was due to the following box and whisker plot in Figure 1, where agreements at and below 24 years are in the lower extreme. Agreements above 24 years are considered average or above, so they will be considered long. Using this box plot was to help mitigate researcher biases and find a natural break in duration. This research also includes cases with a lifespan less than 24 years, making it "short," as, without it, this research has no variability in the dependent variable. Again, longevity does not provide information about compliance to a treaty and is not representative of compliance. This research will include agreements that were disputed but still considered in force. If a treaty was absorbed or had a follow-on agreement, the treaty is considered still in force.[45]

[44] Using a box and whisker plot which plotted the 29 agreements in our dataset based on the number of years in force, agreements at and below 24 years are in the lower extremes of the data.

[45] This research does not control for agreements that have sunset clauses, which is an alternative way to account for this process. Without controlling for the sunsetting of an agreement or absorbing the timeline, these cases would create data discrepancies in this method of analysis.

Figure 1: Box plot showing the years in force for each agreement in this dataset



As mentioned previously, the universe of cases will be Sarah Krep's dataset of 48 agreements, with 29 meeting the condition of having entered into force. Each case is coded by the year it entered into force (EIF), the year the agreement was terminated, the total number of years in force, and whether each condition is present or absent. The full table of cases included in this study is in the appendix.

Results

Using a Qualitative Comparative Analysis (QCA), this research created a truth table for the 29 cases showing the four conditions based on the dependent variable, longevity.[46] The truth table is presented below, which shows all possible pathways, or combinations, in this dataset. The most common path for agreements has positive membership, meaning they include a nuclear-armed state, but no dispute settlement bodies (DSB), verification regimes, or technology transfer mechanisms. The second most common path is positive DSB, verification regimes and membership, but no technology transfer mechanism.

Figure 2: Truth table showing the combination of the four conditions creating pathways to positive longevity

dsb	vfy	mbr	ttm	OUT	n	incl	PRI	cases
0	0	0	0	1	2	1.000	1.000	11,12
0	0	1	1	1	2	1.000	1.000	1,22
0	1	1	0	1	1	1.000	1.000	19
1	0	0	0	1	1	1.000	1.000	13
1	1	1	0	1	8	0.875	0.875	4,6,8,16,17,20,21,24
0	0	1	0	1	9	0.667	0.667	2,5,9,10,15,18,25,28,29
1	0	1	0	1	3	0.667	0.667	7,14,27
1	1	0	0	1	2	0.500	0.500	3,23
0	1	0	0	0	1	0.000	0.000	26

This research then checked for deviant cases. The results are included below, with deviant cases in the DCC column. A full examination of each deviant case can be found

[46] A truth table is a mathematical table used in logic which sets out the functional values of logical expressions on each of their functional arguments, that is, for each combination of values taken by their logical variables. For QCAs, truth tables show which cases had the same combination of the four conditions.

in the appendix. The most common reason for deviancy is an agreement's possible years in force. Most deviant cases are younger than 24 years, meaning it is not possible for that agreement to be considered "long." However, in all cases, it could be assumed these agreements will become long based on other agreements with similar paths, with the exception being the Mongolia NWFZ. This shows that almost all agreements have similar institutional designs, and therefore, most agreements have a long duration.

This research recognizes the issue of time in these deviant cases but removing deviant cases would result in no variability in the dependent variable. This is a limitation of this research and will be discussed further in the Limitations section.

The last step of this QCA is finding the minimization model:

$$dsb + \ -vfy + mbr \ \leftrightarrow dur$$

This model means that a positive dispute settlement body, a lack of verification regimes, and positive membership positively impact the duration of an agreement. Membership is the most significant condition required for positive longevity. The existence of a dispute settlement body and a lack of verification regime is also sufficient for positive longevity but is not a necessary condition. The absence of a technology transfer mechanism is also necessary, but it's only present in two cases. Figure 4 shows one part of the model, with the full model in the appendix.

Figure 3: Minimization model showing the most common pathway and which cases follow each condition in the model

```
M1:    dsb + ~vfy + mbr <-> dur

         inclS   PRI   covS   covU   cases
-------------------------------------------------------------------------------------------------
1   dsb  0.786  0.786  0.500  0.045  13; 7,14,27; 3,23; 4,6,8,16,17,20,21,24
2  ~vfy  0.765  0.765  0.591  0.091  11,12; 2,5,9,10,15,18,25,28,29; 1,22; 13; 7,14,27
3   mbr  0.783  0.783  0.818  0.045  2,5,9,10,15,18,25,28,29; 1,22; 19; 7,14,27; 4,6,8,16,17,20,21,24
-------------------------------------------------------------------------------------------------
     M1  0.786  0.786  1.000
```

The next section will discuss the results in relation to certain agreements and this research's relevancy going forward.

Discussion

The goal of this analysis is to examine the relationship between each component and the outcome of this research, longevity. By determining the most common components and their impact on longevity, this study hopes to find patterns that can be used to create future agreements.

One interesting relationship this study found is the lack of verification leading to the longevity of agreements. This method cannot make this claim that a lack of verification leads to longer duration, but it does show this relationship should be further studied. This section will discuss this relationship in practice and examine the other results.

In 17 out of 29 cases, there are no verification regimes. This includes the Zangger Committee and the Nuclear Suppliers Group, which are voluntary export control regimes. These are considered key export control regimes which created trigger lists that are the

basis for the United States export control regime.[47] However, they do not have verification regimes to ensure compliance but have been in force for 47 and 46 years, respectively. Most treaties that do have verification regimes are agreements between the U.S. and Russia.[48] These verification regimes have evolved over time between the two powers and continue to evolve today. After New START expires in 2026, a new agreement will need to take its place and this question of verification will remain; this research suggests there needs to be a balance between too much and too little verification, especially as technological capabilities increase.

Again, this research cannot claim a lack of verification regime automatically results in longer agreements, but this is an interesting relationship to consider. Again, this research does not discuss compliance, so further research is needed if this relationship holds with compliance. Previous scholarship does attempt to answer this; Reddie found that "arms control regimes with no verification regime are at substantial risk of non-compliance while the most stringent regimes that include challenge inspection regimes also share this risk."[49] His results suggest there is a 'goldilocks' level between too little and too stringent verification regarding compliance.

The complications of too much verification were a topic of concern in the 1990s as well; a discussion of arms control dispute settlements mentioned: "the verification regimes being established in the new agreements are overly complicated and may--as we

[47] Trigger lists are a list of goods that require safeguards to be exported.

[48] Formerly the Soviet Union

[49] Reddie. 2019.

saw in the SALT II ratification process--actually give rise to disputes over technical violations which could potentially undermine the regime."[50] Another possible explanation for this relationship has been stated by Raustiala. "States often compensate for the risk of their own non-compliance by weakening monitoring or watering down commitments."[51] However, due to the binary nature of this research, this paper only identifies this relationship as a basis for further exploration.

The presence of a dispute settlement body (DSB) is also a sufficient condition for positive longevity with 14 out of 29 cases containing one. This means there's a relationship between agreements that contain a DSB and an agreement with a long duration. Every US-Russia agreement contains a dispute settlement body; one example is the INF treaty's Article VIII which created the Special Verification Commission (SVC). Most discussions occurred at the senior level, with the SVC being used only a handful of times.[52] This example of the INF's SVC may imply that formalized avenues for discussions are useful, but high-level discussion may occur anyway. Formalized avenues may be a way to ensure that discussions occur when needed but do not facilitate all discussions between countries. Another example is the IAEA Board of Governors within the NPT that will solve disputes, and the ultimate use of the United Nations Security Council should non-compliance continue. A DSB is a sufficient but not necessary

[50] McNeill et al. 1990.

[51] Raustiala 2005.

[52] Woolf 2019.

condition in this research. The configuration of the dispute settlement body may change this conclusion but is out of the scope of this research due to its binary nature.

The membership of an agreement is also a necessary condition. Agreements that contain at least one nuclear state have a positive effect on duration. In 23 out of 29 agreements, there is at least one nuclear state involved. The few agreements that do not include nuclear weapon states are Nuclear Weapon Free Zones (NWFZs) or agreements preventing nuclear weapon deployment. This may mean agreements are longer when a nuclear weapons state is involved, but there are few agreements without a nuclear state. Given that there are numerous follow-on agreements between the US and Russia, this may mean states that have nuclear weapons must continually work towards stability and transparency, while states without nuclear weapons do not have to continue to update that commitment. Nuclear-armed nations must continue to address technological advances, while states that vowed to never have nuclear weapons are not faced with those same challenges. This paper does not provide an analysis of how many agreements were conducted on a bilateral versus multilateral basis or its effect on longevity. Reddie's research found no significant difference between bilateral or multilateral agreements regarding compliance, but further research is needed.

The absence of a technology transfer mechanism is also a necessary condition for positive longevity, but there are only two cases of its presence. This research cannot draw conclusions based on the small sample number, but it will hypothesize why this mechanism is not widely implemented within arms control agreements. As mentioned before, including a trade component widens the scope of the agreement and would

require including experts on trade facilitation in the negotiation process. There is limited overlap between trade experts and nuclear experts, making these discussions more complicated and less likely, resulting in their exclusion. There are two instances of technology transfer mechanisms outside the scope of this research in cases that were not examined – the Agreed Framework and the JCPOA. It can be argued that these mechanisms were not fully realized and contributed to each agreement's complications and short duration. Since these are outside the scope of this research, this paper will only speculate that these mechanisms could theoretically play a linkage role, but in practice, create more examples of non-compliance and contribute to a short duration.

Given these results, this research faces a significant number of limitations that should be addressed in future research. The next section will discuss key limitations, which aim to be exhaustive, but there are many areas where this research could and should be expanded.

Limitations

This research was limited by a variety of factors. This section will highlight some shortcomings of this paper and explain potential changes given more time and resources. It will also highlight key areas for future research.

This paper recognizes the shortcomings associated with limiting the four variables to a presence/absence scale. The chosen method of analysis can be used with a crisp set, which is what this research considered, or a fuzzy set, which would allow more variation in each variable. Given more time, these variables should be considered based on intensities and run as a fuzzy set. Explanations of each specific change follows.

First, verification regimes across agreements are not equal and should not be considered as such. In previous scholarly research, agreements are analyzed based on verification design characteristics and verification organization.[53] In this research, verification regimes that have specified avenues, including national technical means and on-site verification, are considered similar to regimes that only specify the ability to use national technical means. In practice, the ability to conduct on-site inspections changes the intensity of the agreement. Making this distinction would provide a clearer connection between verification and longevity and could show a "goldilocks" level of verification.

This research also determines membership based on whether a nuclear-armed state is a signatory to the treaty or not. To gain a better sense of what type of membership matters, it should consider whether the treaty was a bilateral or multilateral treaty. From a U.S. perspective, it could also break down membership by which states were included in the agreement. Considering whether an agreement was bilateral, minilateral, or multilateral would provide more insight into how many states are necessary or sufficient for creating long-lasting agreements. Does including more states create more issues, therefore leading to a shorter agreement? Are bilateral treaties more likely to be short because it only takes one nation to end the agreement? These are questions that should be considered in future research.

[53] Andrew Reddie's dissertation breaks down design characteristics into information exchange, on-site inspections, and challenge inspections and verification organizations into tailored institutions that are created on an ad hoc basis and standing intergovernmental organizations.

The last shortcoming of using a presence/absence scale is considering dispute settlement bodies (DSB). This research assumes if there is a separate authority, then there is a DSB. However, there are many treaties that specify an avenue for settling disagreements that do not include creating a separate authority. Outside authorities also play different roles and settle disputes in different ways. In more recent agreements such as the JCPOA, the DSB is a mediator outside of the participants and plays a more active role in the process. This is significantly different from the US-Russian DSBs that remain bilateral. DSBs also differ in the power they are given; some are given the "authority to decide the issue, or merely to find facts or make a recommendation."[54] Again, this condition should be examined based on the intensity of the DSB and its goal, not whether it was absent or present.

This research is also limited by the number of cases available. The entire universe of cases only includes 48 agreements with this research only using 29 cases, which are small sample sizes. A sample size this small can inflate findings or allow a data error to change findings. This can be seen in the necessary condition of a lack of technology transfer mechanism; there are only two examples of this mechanism in the 29 cases examined. As discussed earlier, the technology traded in these two were significantly different. In the Hotline Treaty, the United States provided communication equipment to the Soviet Union. The Trilateral Statement in 1994 transferred funds from the Russians to Ukraine for Ukraine's enriched uranium. Ukraine also transferred the nuclear weapons that remained after the fall of the Soviet Union to Russia. These two examples could be

[54] McNeill et al. 1990

considered atypical of traditional technology transfers; another example not in this dataset is the Agreed Framework that facilitated the construction of a light-water reactor. This construction of technology that contributes to peaceful nuclear energy would be more typical, but eventually fell through and was a contributing factor to the decline of an agreement. Ideally, the number of cases would be much larger to give a complete analysis, and there would be more cases with a technology transfer mechanism.

The dependent variable, longevity, is also a limiting factor in this research. The deviant cases could not be excluded because the variation is limited within agreements. Many of the agreements throughout the late 20th century were concluded between the United States and the Soviet Union, and eventually Russia, with more agreements conducted between non-nuclear states in the 21st century. This does not allow agreements to be considered long because of our duration level of 24 years. Using a dichotomous dependent variable could have also skewed the results. This research coded agreements that were absorbed by other agreements as still in force, as without that they became deviant cases that could only be explained by their successor treaty. Treating them as short treaties could change conclusions in other methods. Future research could also use a hazard model instead of using this dichotomous coding scheme. The focus on longevity also does not give insights into compliance or how compliance and longevity relate. Agreements may be long, but have limited compliance, making their utility questionable. Future research should consider this relationship with compliance and run this analysis for both compliance and longevity.

Lastly, there is limited scholarly work done on this topic using a quantitative approach. This research uses Dr. Andrew Reddie's work to compare findings. It also used Dr. Sarah Krep's dataset to determine the universe of cases, limiting which agreements were included or excluded. There can be arguments as to whether certain cases should have been excluded, however this research decided to include as many as reasonably possible to remain replicable. There should be more quantitative research done on the institutional design of arms control agreements to fully draw conclusions and provide implications. While our results were similar, Dr. Reddie used a different method of analysis and Dr. Kreps used different design components and a different method of analysis. Again, our research should be replicated, recognizing these limitations.

Conclusion

Based on this research, the institutional design of arms control agreements does play a role in the longevity of an agreement. Including at least one nuclear armed state in the agreement is necessary to produce a longer agreement. A lack of technology transfer mechanism and the presence of a dispute settlement body also contributes to positive longevity. The most interesting relationship is a lack of verification regime contributing to positive longevity, implying agreements may last longer without verification regimes. This may play into the 'goldilocks' idea that there is an ideal level of verification; too little verification may not provide enough confidence in the agreement itself and too stringent verification may be perceived as impeding national sovereignty or create more concerns and decrease the lifespan of an agreement. While longevity is not often the goal

of agreements, it does show the utility of the agreement to each state, and can allow for future discussions and agreements to occur.

There are numerous areas for future research in this field. There has been very little research done on the institutional design of arms control agreements and should be considered as technology advances and challenges current agreements. Accounting for increased missile defense technology, low-yield nuclear weapons, and competition in different domains including space will enhance stability going forward. Future arms control agreements should include dispute settlement bodies that can provide a forum to discuss destabilizing technology and find a middle ground of verification for these new technologies while respecting the sovereignty of each nation. Creating stronger, and longer, agreements will contribute to more stability going forward.

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Appendix A: Deviant Case Discussion

This section provides a further discussion of deviant cases and the reasoning for each deviant case.

The first deviant case is the Trilateral Comprehensive Test Ban Negotiations (case 24). It entered into force in 1997 and is still in force. However, since it entered into force in 1997, its duration has been 24 years. It is considered short based on this research, but it has only had the opportunity to be in force for 24 years. Assuming it continues to remain in force, it is expected it could follow other cases with similar paths and become a long agreement. Its path of positive DSB, verification regimes, membership, but no technology transfer mechanism is the second most common path of all agreements, with seven of the eight being considered long in duration. This path is the same as the NPT, ABM Treaty, SALT I, INF, PNET, CFET, and START I. Had this treaty entered into force one year earlier numerically, it would not be a deviant case, so it does not impede the previous results.

Similarly, the Lahore Declaration (case 25), Proliferation Security Initiative (case 28), and UNSCR 1540 (case 29) are deviant cases due to their entry in force year but represent the most common path. There are six other cases that have the same path and have been in force for over 24 years.

The SORT treaty (case 27), which entered into force in 2002, is also a deviant case. Similar to the previous case, it has not had the opportunity to be in force for more than 24 years, so it is considered deviant. The Seabed Treaty and the Convention on Physical Protection of Nuclear Material have the same path and are long in duration. This

could allow for the assumption that this treaty will continue to remain in force and become a long treaty.

The Treaty of Bangkok (case 23) is also a deviant case due to the same issue explained previously; it entered into force in 1997, meaning it cannot be considered a long treaty. However, it has the same path as the Treaty of Tlatelolco, which has remained in force for 52 years.

Lastly, the Mongolia NWFZ is a deviant case and has its own path. Again, it faces the issue of entry into force year, meaning it cannot be longer than 21 years because it entered into force in 2000. However, it is also a unique case because it is not a nuclear country but includes a verification regime to ensure it remains free of nuclear weapons. It differs from other NWFZ agreements because it does not include a dispute settlement body since it's one nation.

Appendix B: Other Figures

Figure 4: Cases included in this research

Treaty	Year EIF	Year Terminated	Years in Force	Long or Short	DSB	Verification Regime	Membership	Tech Transfer Mechanism
Hotline Treaty	1963	0	58	1	0	0	1	1
Outer Space Treaty	1967	0	54	1	0	0	1	0
Treaty of Tlatelolco	1969	0	52	1	1	1	0	0
NPT	1970	0	51	1	1	1	1	0
Accident Measures Agreement	1971	0	50	1	0	0	1	0
ABM Treaty	1972	2002	30	1	1	1	1	0
Seabed Treaty	1972	0	49	1	1	0	1	0
Interim Agreement US-USSR (SALT I)	1972	0	49	1	1	1	1	0
Zangger Committee	1974	0	47	1	0	0	1	0
Nuclear Suppliers Group	1978	0	46	1	0	0	1	0
Moon Agreement	1984	0	37	1	0	0	0	0
Prevention of Nuclear War Agreement	1984	0	37	1	0	0	0	0
Treaty of Rarotonga	1986	0	35	1	1	0	0	0
Convention on the Physical Protection of Nuclear Material	1987	0	34	1	1	0	1	0
Missile Technology Control Regime	1987	0	34	1	0	0	1	0
Intermediate Range Nuclear Forces (INF) Treaty	1988	2019	31	1	1	1	1	0
Peaceful Nuclear Explosion Treaty	1990	0	31	1	1	1	1	0
India-Pakistan Non-Attack Agreement	1991	0	30	1	0	0	1	0
Lisbon Protocol	1991	0	30	1	0	1	1	0
Conventional Forces in Europe Treaty	1992	0	29	1	1	1	1	0
START I	1994	0	27	1	1	1	1	0
Trilateral Statement	1994	0	27	1	0	0	1	1
Treaty of Bangkok (Southeast Asia NWFZ)	1997	0	24	0	1	1	0	0
Trilateral Comprehensive Test Ban Negotiations	1997	0	24	0	1	1	1	0
Lahore Declaration	1999	0	22	0	0	0	1	0
Mongolia Nuclear Weapon Free Zone	2000	0	21	0	0	1	0	0
SORT	2002	0	19	0	1	0	1	0
Proliferation Security Initiative	2003	0	18	0	0	0	1	0
UNSC Resolution 1540	2004	0	17	0	0	0	1	0

Figure 5: Agreements coded in R

X	Treaty	Year.EIF	Year.Terminated	yif	dur	dsb	vfy	mbr	ttm
<int>	<chr>	<int>	<int>	<int>	<int>	<int>	<int>	<int>	<int>
1	Hotline Treaty	1963	0	58	1	0	0	1	1
2	Outer Space Treaty	1967	0	54	1	0	0	1	0
3	Treaty of Tlatelolco	1969	0	52	1	1	1	0	0
4	NPT	1970	0	51	1	1	1	1	0
5	Accident Measures Agreement	1971	0	50	1	0	0	1	0
6	ABM Treaty	1972	2002	30	1	1	1	1	0
7	Seabed Treaty	1972	0	49	1	1	0	1	0
8	Interim Agreement US-USSR (SALT I)	1972	0	49	1	1	1	1	0
9	Zangger Committee	1974	0	47	1	0	0	1	0
10	Nuclear Suppliers Group	1978	0	46	1	0	0	1	0
11	Moon Agreement	1984	0	37	1	0	0	0	0
12	Prevention of Nuclear War Agreement	1984	0	37	1	0	0	0	0
13	Treaty of Rarotonga	1986	0	35	1	1	0	0	0
14	Convention on the Physical Protection of Nuclear Material	1987	0	34	1	1	0	1	0
15	Missile Technology Control Regime	1987	0	34	1	0	0	1	0
16	Intermediate Range Nuclear Forces (INF) Treaty	1988	2019	31	1	1	1	1	0
17	Peaceful Nuclear Explosion Treaty	1990	0	31	1	1	1	1	0
18	India-Pakistan Non-Attack Agreement	1991	0	30	1	0	0	1	0
19	Lisbon Protocol	1991	0	30	1	0	1	1	0
20	Conventional Forces in Europe Treaty	1992	0	29	1	1	1	1	0
21	START I	1994	0	27	1	1	1	1	0
22	Trilateral Statement	1994	0	27	1	0	0	1	1
23	Treaty of Bangkok (Southeast Asia NWFZ)	1997	0	24	0	1	1	0	0
24	Trilateral Comprehensive Test Ban Negotiations	1997	0	24	0	1	1	1	0
25	Lahore Declaration	1999	0	22	0	0	0	1	0
26	Mongolia Nuclear Weapon Free Zone	2000	0	21	0	0	1	0	0
27	SORT	2002	0	19	0	1	0	1	0
28	Proliferation Security Initiative	2003	0	18	0	0	0	1	0
29	UNSC Resolution 1540	2004	0	17	0	0	0	1	0

29 rows

The following figures are outputs of necessity and sufficiency analyses.

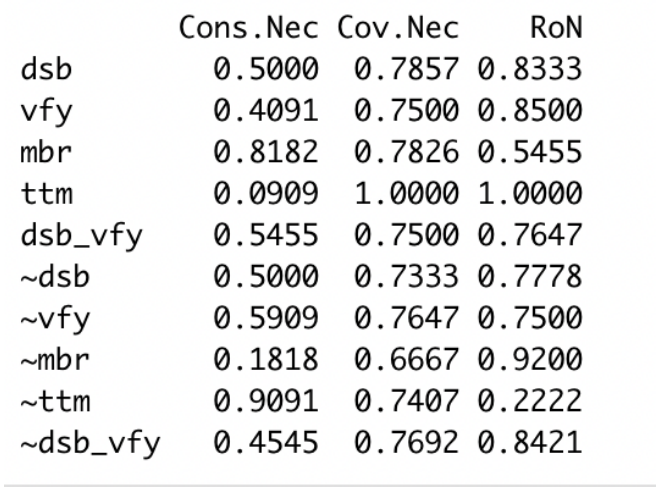
	Cons.Nec	Cov.Nec	RoN
dsb	0.4286	0.2143	0.5769
vfy	0.4286	0.2500	0.6538
mbr	0.7143	0.2174	0.2500
ttm	0.0000	0.0000	0.9310
~dsb	0.5714	0.2667	0.5600
~vfy	0.5714	0.2353	0.4800
~mbr	0.2857	0.3333	0.8519
~ttm	1.0000	0.2593	0.0909

Figure 6: Analysis of Necessity

Figure 7: Negated Necessity Analysis

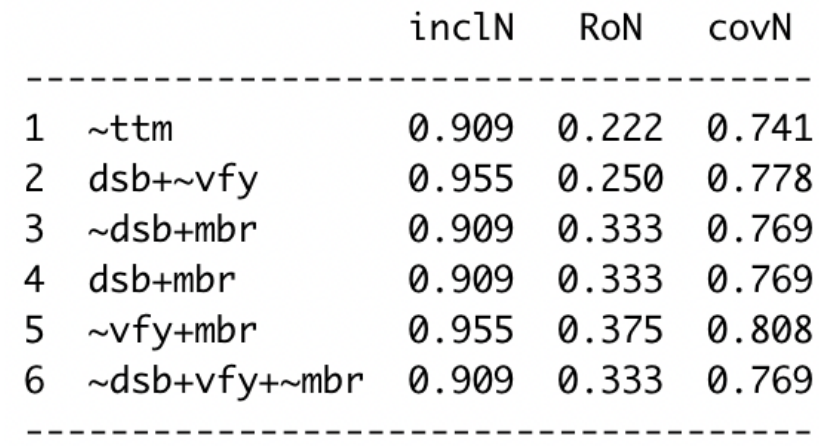
	Cons.Nec	Cov.Nec	RoN
dsb	0.5000	0.7857	0.8333
vfy	0.4091	0.7500	0.8500
mbr	0.8182	0.7826	0.5455
ttm	0.0909	1.0000	1.0000
~dsb	0.5000	0.7333	0.7778
~vfy	0.5909	0.7647	0.7500
~mbr	0.1818	0.6667	0.9200
~ttm	0.9091	0.7407	0.2222

Figure 8: Analysis of Necessity



	Cons.Nec	Cov.Nec	RoN
dsb	0.5000	0.7857	0.8333
vfy	0.4091	0.7500	0.8500
mbr	0.8182	0.7826	0.5455
ttm	0.0909	1.0000	1.0000
dsb_vfy	0.5455	0.7500	0.7647
~dsb	0.5000	0.7333	0.7778
~vfy	0.5909	0.7647	0.7500
~mbr	0.1818	0.6667	0.9200
~ttm	0.9091	0.7407	0.2222
~dsb_vfy	0.4545	0.7692	0.8421

Figure 9: Analysis of Necessity including the Disjunction



		inclN	RoN	covN
1	~ttm	0.909	0.222	0.741
2	dsb+~vfy	0.955	0.250	0.778
3	~dsb+mbr	0.909	0.333	0.769
4	dsb+mbr	0.909	0.333	0.769
5	~vfy+mbr	0.955	0.375	0.808
6	~dsb+vfy+~mbr	0.909	0.333	0.769