A Bargaining Model of Nuclear Weapons Development and Disarmament*†

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Abstract

This paper addresses four questions about leaders' rationales and strategies for developing and confronting nuclear weapons programs. First, why do governments develop nuclear weapons? Second, under what conditions will governments attack nuclear aspirants to prevent or remove their weapons programs? Third, why do aspirants sometimes develop nuclear weapons ambiguously? Fourth, why do counter-proliferators offer inducements to aspirants? We develop a game-theoretic bargaining model to study these issues. Two governments, an aspirant and a counter-proliferator, bargain over the aspirant's nuclear program. The aspirant has private information about its preferences for developing nuclear weapons. It can be either a "normal" type, which benefits little from having nuclear weapons, or a "motivated" type, which seeks weapons for intrinsic or instrumental value. The counter-proliferator decides whether to pay or force the aspirant to disarm. Inducements can be effective under some circumstances.

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1 Introduction

In a speech to the UN in September 2009, President Obama outlined the urgency of the threat of nuclear proliferation and made known his goal for a world free from nuclear weapons. As steps toward that goal, the US recently agreed to a disarmament deal with Russia, hosted an international nuclear-security summit to prevent nuclear material from falling into the hands of terrorist threats, and pushed for new United Nations sanctions against Iran's nuclear programs. Whether these efforts will actually stem the spread of nuclear weapons remains to be seen, but the widespread attention paid to these matters underscores the gravity of the general issue of nuclear proliferation.

Nuclear proliferation remains one of the gravest international security concerns. In the four decades since the Nuclear Nonproliferation Treaty (NPT) came into force in 1970, the number of nuclear capable states has grown. Many states, which currently do not possess nuclear weapons, aspired or attempted to acquire nuclear capability at some point. And, states have clashed militarily and diplomatically over weapons and nuclear programs. These facts lead us to ask why governments continue to develop nuclear weapons. An equally important question is why many states do not choose to develop weapons, since the number of nuclear capable states has increased by only four since the NPT.

Many efforts to contain proliferation have focused on controlling, containing, and reducing the spread of nuclear materials and knowledge. Signatories to the NPT commit to the peaceful use of nuclear technology subject to the standards of the International Atomic Energy Agency, which monitors nuclear facilities and tracks the development and flow of fissile material. Academic centers and independent organizations focus research and outreach efforts on improving information and spreading norms about such counter-proliferation efforts.[1] Additionally, recent scholarship that examines the effectiveness of counter-proliferation focuses on controlling the spread of materials and technology. These studies find that external cooperation and provision of sensitive nuclear technology and material is a strong determinant of states' decisions to develop nuclear weapons (see Kroenig in this volume; Fuhrmann this volume).

Working to deny nuclear aspirants the material and know-how to arm themselves is one aspect of nuclear counter-proliferation. Another side is strategic denuclearization and bargaining. Thomas Schelling pointed out that "the emphasis has to shift from physical denial and technology secrecy to the things that determine incentives and expectations" (Schelling 1976: 30; quoted in Solingen 2008: 7). Governments determined to arm themselves have shown their ability to acquire nuclear weapons technology in spite of the NPT (e.g., North Korea, India, and Pakistan). Yet, many technically sophisticated governments have chosen not to weaponize (e.g., Japan and Germany). Some governments have decided to abandon programs midstream (e.g., South Korea, Taiwan, and Libya) or even after they have already developed weapons capability (e.g., South Africa). And, some governments have shielded their programs behind a wall of ambiguity (e.g., Israel and North Korea pre-test). To understand why these strategies are adopted and when they are more or less effective, it is important to examine aspirants' incentives.

It is also critical to analyze these decisions within the context of denuclearization strategies, which counter-proliferators formulate in enviornments of limited information. Since the introduction of the NPT, denuclearization efforts have mostly involved powerful nuclear powers (counter-proliferators) targeting relatively weaker aspiring nuclear powers (aspirants) to prevent them from acquiring weapons. Because aspirants typically do not cooperate with the NPT, weaponization efforts are generally not verifiable. Nor are counter-proliferators certain about the motives and potential threat posed by an aspirant should it achieve nuclear weapons. Under such conditions of limited information, counter-proliferators have, at various times, adopted a range of denuclearization strategies including direct military strikes, sanctions, diplomatic condemnation and pressure, and concessions. In addition to these strategies, counter-proliferators have also sometimes stood by and watched aspiring nuclear powers develop nuclear weapons without making any meaningful effort to counter. Aspirants respond to these various strategies differently, sometimes capitulating and sometimes pushing forward with their nuclear designs. In this chapter, we study the strategic interaction between counter-proliferators and aspirants. In particular, we focus on four specific questions. Why do aspirants choose to develop nuclear weapons? Under what conditions will counter-proliferators resort to military force to prevent aspirants from arming? Why do aspirants sometimes develop weapons ambiguously? And, when will counter-proliferators find it optimal to make concessions in exchange for cooperation?

To address these questions, we develop a two-player bargaining model. There are few formal theories of nuclear proliferation and counter-proliferation. Baliga and Sjostrom (2008) is a recent stand-out. This model shows that nuclear ambiguity gives aspirants security benefits without their actually having to develop a verifiable nuclear deterrent. Our model concentrates on the bargaining aspects of nuclear armament and disarmament, in order to determine whether nuclear ambiguity is a useful strategy for extracting concessions from counter-proliferators.

Our analysis shows decisions to arm depend on the presence of security threats or overriding interests in possessing nuclear weapons. These predictions are well-supported in the empirical literature. We analyze two different counter-proliferation measures: preventative military strikes and concessions. Preventative military measures will be taken when counter-proliferators believe proliferators are highly motivated to possess nuclear weapons, they feel threatened by proliferation, and their costs for undertaking preventative military strikes are relatively low. In analyzing the preventative military option, we identify a nuclear security dilemma, in which nuclear aspirants arm in response to the fear they will be attacked, but counter-proliferators threaten to attack in order to prevent aspirants from becoming armed and dangerous. As an alternative to military measures, governments can also grant inducements in exchange for verifiable disarmament. Counter-proliferators will offer concessions to gain cooperation when nuclear aspirants' motivations for acquiring weapons are not so high that the bribe is not cost-efficient.

We first describe the set-up of the model. Then we analyze aspirants' decisions to arm themselves with nuclear weapons. Next, we discuss when counter-proliferators might find it optimal to attack nuclear aspirants. Finally, we examine an ambiguity equilibrium in which aspirants' unpredictable behavior results in counter-proliferators offering inducements in exchange for verifiable denuclearization. We illustrate the intuition of these results with examples.

2 The Model

There are two governments, A, the counter-proliferator, and B, the aspirant. Government A is the more powerful of the two. Initially, B is not armed with nuclear weapons, and A is interested in persuading B not to arm. Government B can invest in nuclear weapons at a cost of $\kappa > 0$. We assume that B successfully acquires weapons if it chooses to arm. If it chooses not to arm, then it incurs no costs and it does not acquire nuclear weapons. Government A cannot observe B's decision to arm, and its uncertainty about whether B has or has not armed gets resolved at the end of the game.

Government A decides whether to attack B or to make an offer to B in exchange for giving up its weapons and allowing external verification. Since A is stronger, we assume it will win a war against B, but attacking is costly. Government A pays c_A if it attacks an armed B and attacking an unarmed B costs c_{NA}. Since attacking an unarmed opponent is less dangerous, we assume $c_A > c_{NA} > 0$. It is better for B to have weapons if it is attacked, since it can use its advanced technology in a war. Thus, B gets a benefit γ if it is attacked when it is armed, and B always pays a cost β to fight a war regardless of whether it is armed. We assume that $\gamma > \kappa$, which implies that in war the benefits of having advanced weapons outweights the costs of developing them. If A attacks, the game ends, and payoffs are as follows:

B is armed	B is unarmed
$1 - c_A, \gamma - \kappa - \beta$	$1 - c_{NA}, -\beta$

As an alternative to attacking, A can make an offer $x \in [0, 1]$ to convince B to give up its weapons and allow external verification that it is not armed. In practice, an offer might include security assurances, normalized diplomatic relations, peaceful nuclear capability, or direct monetary transfers. Once an offer is made, B can either accept or reject the offer. Rejecting means B retains weapons if it is armed, or it gets nothing if it is not armed. Developing and keeping weapons can provide leaders with many benefits. Several studies have discussed leaders' motivations for developing nuclear weapons. Reasons for weaponizing include deterrence, domestic pressures, international prestige (Sagan 1996/1997), regime type, domestic economic factors, and considerations of political survival (Solingen 2007). Additionally, states may develop weapons because they are valuable bargaining chips for achieving concessions from counter-proliferators. Whatever their motivations, governments arm because they perceive they can derive direct or instrumental value from having nuclear weapons. In developing a general theory, we do not focus on any specific motivating reason, but instead we concentrate on how intensely governments want nuclear weapons. All else equal, a government which has moderate deterrence concerns may be less likely to acquire nuclear weapons than a government which faces intense domestic pressures for political survival, and vice versa. Thus, prospective proliferators in our model differ according to how much utility they receive from successfully acquiring nuclear weapons. Accordingly, government B's value of keeping weapons if it rejects an offer is δ_t, where t denotes government B's type. The higher δ_t the more B values having nuclear weapons for whatever reason.

Since our model analyzes the interaction between a government which appears to aspire to achieve nuclear weapons and another government which does not want the aspirant government to be armed, then it must be that government A suffers some cost if B develops and keeps weapons. This cost, represented by the parameter w_t, represents the amount of A's worry or its perceived level of threat from government B possessing nuclear weapons. Worry can be tied to several factors including the direct threat posed by an adversary possessing nuclear weapons, the threat to allies, and political concerns about the impact on one's influence as a result of shifts in relative power. For example, China's nuclear test in 1964 increased the USSR and India's worry about the direct nuclear threat posed by China while the United States worried more about China's threat to its East Asian allies and to its own relative influence in the region (Burr and Richelson 2000/01). India worried that China's transfer of nuclear materials to Pakistan in the 1990s would both pose a direct threat to India and also reduce its influence in Southeast Asia (Perkovich 1999). Our argument attempts to capture the intuition that counter-arming strategies are a function of how much a government worries about the threat posed by another state having nuclear weapons. Therefore, in the model, government A suffers w_t if B arms and rejects an offer. If A makes an offer to B, then payoffs are as follows:

armed B accepts	unarmed B accepts	armed B rejects	unarmed B rejects
$1-x, x-\kappa$	$1-x, x$	$1-w_t, \delta_t-\kappa$	$1, 0$

Among nuclear powers and those attempting to develop nuclear weapons, there is clear variation across both δ_t and w_t. Governments vary both in terms of how motivated they are to have nuclear weapons and how much of a threat they pose to other states. It is reasonable to assume that Japan had lower δ_t than China since the end of WWII. There is and has been strong public opposition to nuclear weapons in Japan, it formally adopted a resolution committing not to possess or tolerate nuclear weapons in its territory, and is shielded by the US security umbrella from many security threats (Berger 1993; Hughes 2007). By contrast, China, which tested nuclear weapons for three decades after its first test in 1964, was motivated by its aspirations of increasing its influence in the Communist bloc and the East Asia region, being admitted to the UN and achieving recognition as a great power, and securing its defense from both nuclear superpowers – the US and the USSR (Halperin 1965; Lewis and Xue 1988). India, like China and unlike Japan, is another government which could be said to have high δ_t during the decades leading up to its 1998 nuclear tests. In addition to having a nuclear neighbor in China on its north border and a nuclear aspirant rival in Pakistan on its northwestern border, India also was driven by nationalist aspirations to achieve major power status and to buck the nonproliferation regime, which it perceived to be an unfair vestige of western colonialism (Perkovich 1999).

There are also meaningful differences between the amount of threat posed by different states possessing nuclear weapons, which is the parameter w_t for government A's worry or its perceived threat from an armed B. For example, it is reasonable to assume Israel is relatively unthreatened by North Korea having weapons, but it clearly believes a nuclear Iran is dangerous for its own security. Therefore, in interpreting the parameters in the model, aspirants like China or India have higher δ_t than Japan, and Israel would suffer higher w_t if Iran acquires nuclear weapons than if North Korea arms.

Government A does not know B's benefits from arming. Accordingly, government B has two possible types: motivated (type Z) or normal (type N). We call a government "motivated" if it is strongly motivated to acquire nuclear weapons. Government B has a prior probability p_Z of being motivated, and it is normal with probability $1 - p_Z$. Both governments' payoffs depend on B's type. A motivated type B derives more benefit from nuclear weapons than a normal type, and government A only worries if a motivated type has weapons since a normal type does not pose a threat. Thus, we make the following assumptions: $\delta_Z > \delta_N = 0$ and $w_Z > w_N = 0$.

To summarize, we consider the following game of incomplete information, which is depicted in Figure 1:

1. Nature determines the type of B, $\Pr(t = Z) = p_Z$ and $\Pr(t = N) = p_N = 1 - p_Z$.

2. After knowing its type, B chooses to arm (at cost $\kappa > 0$) or not to arm (at no cost).

3. A does not observe B's type and action, A may either attack or offer some x to B.

    3.1 If A attacks, the game ends.

    3.2 If A offers x, B may accept or reject.

As described, we make the following assumptions on the parameters:

A's parameters	B's parameters
$c_A > c_{NA} > 0$	$\delta_Z > \delta_N = 0$
$w_Z > w_N = 0$	$\gamma > \kappa > 0$

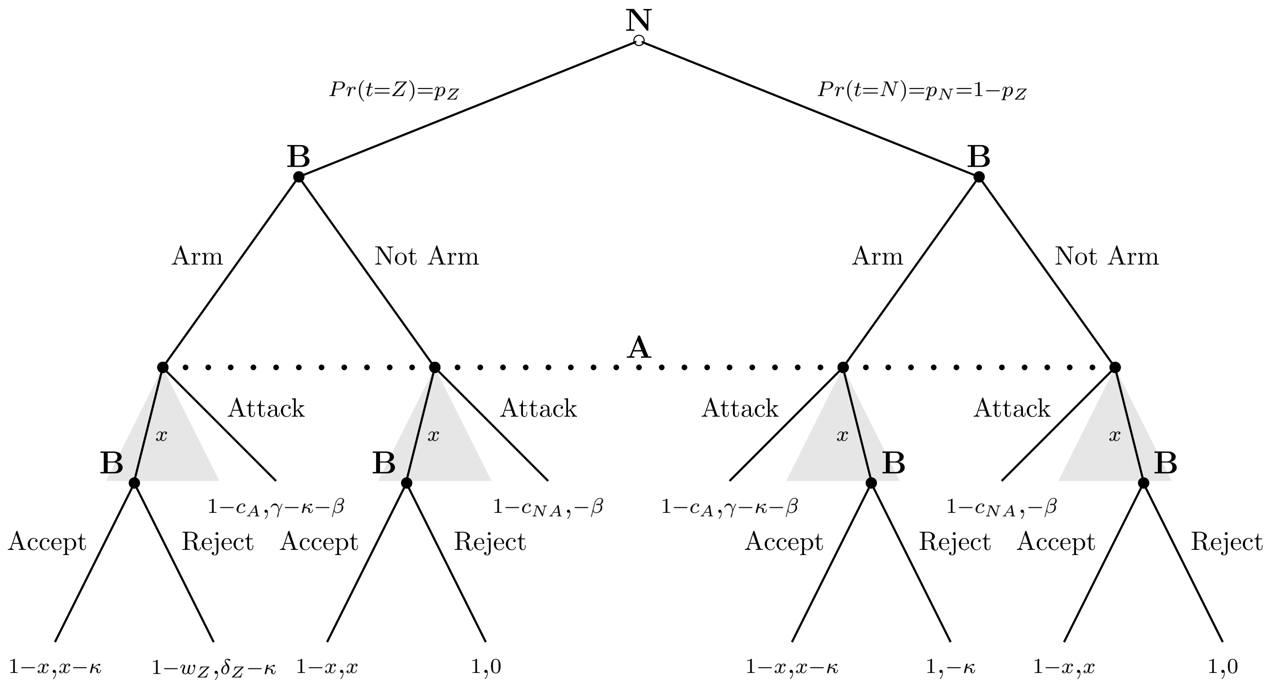

Figure 1: Nuclear bargaining game.

3 Developing Nuclear Weapons

In this section, we address the question about why governments choose to develop nuclear weapons. We can evaluate this problem by analyzing the pure strategy Nash equilibria of the bargaining game. There are three pure strategy equilibria. For simplicity, we label these equilibria: WAR, PEACE, and WMD. Formally, we have the following:

Proposition 1 *There are three possible types of pure strategy equilibria.*

1. *(WAR) There is a pure strategy equilibrium where both types arm and A attacks when* $c_A \leq \min\{p_Z w_Z, \delta_Z\}$*, i.e.,*

$$w_Z \geq \frac{c_A}{p_Z} \quad \text{and} \quad \delta_Z \geq c_A. \tag{1}$$

2. *(PEACE) There is a pure strategy equilibrium in which neither type arms, and A does not attack but also does not offer anything when* $\delta_Z \leq \kappa$*.*

3. *(WMD) There is a pure strategy equilibrium in which the motivated type arms while the normal type does not, and A does not attack but does not offer anything when*

$$w_Z \leq \tilde{c}/p_Z \quad \text{and} \quad \delta_Z \geq \max\{p_z w_Z, \kappa\}, \tag{2}$$

where $\tilde{c} = p_z c_A + p_N c_{NA}$.

Proof. In Appendix. ■

These three pure strategy equilibria are illustrated in Figure 2 where B's investment costs are greater than A's war costs ($\kappa > c_A$). The WAR equilibrium occurs when the probability B is a motivated type is high, a motivated type's value for having nuclear weapons capability is high, and A's worry about a motivated type having weapons is also high. In this equilibrium, both types of B will arm, because B expects A to attack. In the PEACE equilibrium, neither type of B arms and, consequently, A has no reason to attack. As can be seen in Figure 2, this equilibrium obtains when a motivated type's value for possessing nuclear weapons capability is lower than its costs for investing in them. The WMD equilibrium is a separating equilibrium, in which a motivated type arms, because its value for possessing a nuclear weapons capability is high. However, a normal type does not arm, because A's belief and worry that B is a motivated type are low enough that it will not attack.

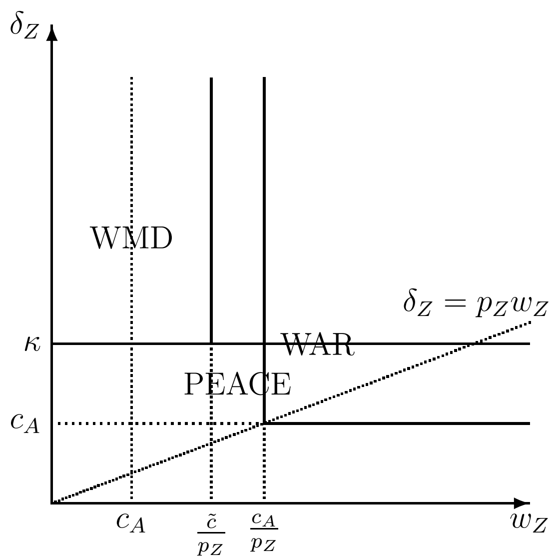

Figure 2: Pure Strategy Nash Equilibria.

Two implications are worth highlighting in greater detail. First, even though we have introduced a bargaining move to the model, there is not a pure strategy equilibrium in which government A offers positive concessions to B. Notice that armed B accepts A's offer if and only if $x \geq \delta_t$, and unarmed B accepts any offer $x \geq 0$. Since $\delta_Z = 0$, government A

does not make a positive offer to a normal type and offers an inducement $x \geq \delta_t$ only if it believes B is a motivated type. However, if A is going to make an offer, B is better off avoiding investment costs by not arming. But, if B does not arm, then A offers nothing. Therefore, government A never offers concessions in pure strategy equilibrium. As a result, for aspirants, arming with certainty for the sake of extorting benefits from concerned counter-proliferators in exchange for verifiable disarmament is not an equilibrium strategy. As we show below, government A is more likely to offer concessions when it is uncertain about B's decision to arm.

Second, the model identifies a nuclear security dilemma. A motivated type B will always arm if its value for possessing nuclear weapons is sufficiently high relative to its costs for investing in weapons. Otherwise, under peaceful circumstances, arming is too costly. However, a motivated type with higher investment costs than value for nuclear weapons will nevertheless arm if it believes A is likely to attack. A normal type government B does not have an incentive to arm in pure strategies *unless* it believes A is going to attack, in which case it is always better for B to arm. Hence, all types of aspirant governments B will develop nuclear weapons when they expect government A to attack. Yet, the A in our model is not inherently aggressive. It will only attack if it believes B is motivated and it worries that B having weapons is dangerous. Otherwise, it will not attack if it is certain B is a normal type or if it is not worried about a motivated type having nuclear weapons. Therefore, A attacks when it perceives B is likely to be armed and dangerous, and B arms when it fears A is going to attack.

This finding implies that nuclear weapons development pays when governments feel sufficiently threatened that having advanced weapons technology will benefit them in a war. Since B arms no matter what when A is a threat and A is a threat when it believes B is a threat, then rivalries should be strong empirical determinants of nuclear proliferation. This result is strongly supported in the quantitative literature. Singh and Way (2004) find that factors related to the external security environment are associated with states' decisions to acquire weapons. Participation in ongoing rivalries and the frequency of militarized disputes in the five years prior to acquisition strongly correlate with weapons development and acquisition. The analysis in Kroenig (this volume) is consistent. Since A is more likely to attack and therefore threaten B when its costs for fighting are low, we should expect proliferation to be especially likely among states facing stronger powers. Jo and Gartzke (2007) show that states facing threats from states with significant conventional weaponary is the strongest determinant of nuclear proliferation. Interestingly, states facing nuclear powers are less likely to develop weapons. Nevertheless, the general prediction that states in threatening security environments are more likely to develop nuclear weapons is, therefore, relatively uncontroversial in the literature. Somewhat related is the finding in Fuhrmann (this volume) that prospective proliferators are more likely to get support for their nuclear programs when they have a superpower enemy and their supplier shares that enemy. Common enemies often pose common security threats, and cooperation on nuclear development can neutralize the common threat both for the supplier and the recipient of nuclear cooperation.

In addition to these noteworthy points, the results described in Proposition 1 (Appendix) also explain other stylized facts about nuclear proliferation. The PEACE and WMD equilibria straight-forwardly establish that unthreatened aspirants will not arm when the costs outweigh the benefits, but motivated types will arm when the benefits of weapons outweigh development costs even when they expect A is not a threat to their security. The majority of the quantitative empirical literature is devoted to testing this basic prediction. Scholars have argued that many factors increase an aspirant's benefit from nuclear weapons. Jo and Gartzke (this volume) test a number of these claims. They find that democracies, which presumably create more pressure for leaders to acquire weapons, are more likely to acquire weapons once they have begun a nuclear program. The analysis also shows that major powers and regional powers are more likely to have weapons, which lends some support to the argument that governments' motivations for international prestige can drive them to proliferate. Factors that reduce the benefits from weapons include NPT membership and having a defense pact with a nuclear defender. In most cases, signing the NPT likely signals a government's lack of interest in weapons technology, and having a nuclear defender provides many benefits of nuclear weapons without governments actually having to incur the costs of development.

Of course, the other side of equation impacting decisions to proliferate contains the costs of development. Factors that reduce development costs include the wealth or economic capacity of a country and whether the country's industrial capacity to support a nuclear program including domestically produced steel, electricity, uranium deposits, scientific experts, etc. When these cost-saving advantages are present, a government is more likely to develop nuclear weapons (Singh and Way 2007; Jo and Gartzke in this volume; and Kroenig in this volume). As Kroenig (this volume) shows, governments that have external suppliers who provide them with sensitive nuclear materials are dramatically more likely to proliferate. Not only does nuclear aid increase proliferation, but so does external assistance and cooperation (Fuhrmann in this volume). These short-cuts to development provide a significant reduction in costs for aspirants and, therefore, increase their willingness to arm.

4 Preventative Military Strikes

The pure strategy equilibria also enable us to draw some conclusions about when we might expect a counter-proliferator to attack a nuclear aspirant. Consider why a counter-proliferator might allow an aspirant to acquire weapons. Condition (2) of the WMD equilibrium (Appendix) implies counter-proliferators will stand by and allow nuclear aspirants to acquire weapons for one of a few possible reasons. First, the costs of bribing aspirants with inducements to give up an incipient weapons program are too high (since aspirants are highly motivated to possess the weapons). Second, counter-proliferators' expected costs for striking and fighting against a motivated type are higher than their worry for allowing a motivated type to possess the weapon. Third, counter-proliferators do not believe the target state is a motivated type of aspirant. When these conditions fail to obtain, then A's decision to attack B to remove its weapons forcibly becomes an option. We should expect to observe strikes by counter-proliferators on aspirants when counter-proliferators believe B is a motivated type, A's threat from an armed motivated type is high, and A's costs for striking B are relatively low.

Arguments to use preventative military force to remove nuclear weapons or to halt their development have been framed in terms of these conditions. For example, at the present time, there is a debate about whether Israel will strike Iran to eliminate its nuclear program. Israel has resorted to military force before, wiping out Iraq's nuclear reactor in Osirak in 1981 and striking a nuclear reactor in Syria in 2007. Former Israeli Defense Minister, Brigadier General Ephraim Sneh (2010) summarized the factors which will affect Israel's decision, and the calculation roughly tracks the equilibrium conditions for preventative strikes. In an oped piece in the Israeli left-wing daily, *Haaretz*, Sneh argues that disarming Iran is urgent for Israeli security, military strikes on Iran would "cripple [Iran's] nuclear project for a number of years," and "the retaliation against Israel would be painful, but bearable." Sneh's key point is that he believes Iran will soon be armed, a weaponized Iran is a significant threat to Israel, and the costs to Israel of attacking Iran are relatively low. This leads Sneh to conclude that, barring a change in these factors, Israel will likely attempt to remove forcibly Iran's nuclear program. Raas and Long (2007) lend some support to this conclusion. In a comparison of Israel's attack on Osirak in 1981 and a potential strike against Iran today, they conclude that even though Iran's nuclear sites are more difficult to attack than the reactor at Osirak, Israeli forces have improved since 1981 to the point that "The operation would appear to be no more risky than Israel's 1981 attack on Iraq's Osirak reactor, and it would provide at least as much benefit in terms of delaying Iranian development of nuclear weapons" (p. 24). If this assessment is correct, then the results of the model suggest Israel's threat to attack Iran is a definite possibility that depends on how costly a preventative war with Iran would be.

Levy (2008) argues that states' decisions to undertake preventative attacks are not as constrained by normative inhibitions or democratic institutions as once supposed. Instead, such decisions hinge on the kind of cost-benefit calculation we identify. According to Levy, the US decisions to attack in the 1990-91 Persian Gulf War and 2003 Iraq War were built on public support for eliminating Iraq's threat of nuclear weapons. However, sometimes the costs of preventative strikes are too high, and counter-proliferators will decide against attacking after assessing the costs. During the 1993-1994 crisis over North Korea's nuclear weapons, President Bill Clinton seriously weighed the option of launching air strikes against North Korea's nuclear reactor at Yongbyon. Administration officials estimated the war would result in "52,000 US troops killed or wounded, 490,000 Republic of Korea military casualties, "enormous" numbers of North Korean and civilian deaths, and a $61 billion cost, mostly to be paid by the US" (Levy 2008, 18; Oberdorfer 1997, 315; Sigal 1997, 211-212). This price was too high to pay, especially in constrast to the costs of the alternative strategy, which was to offer the inducements layed out in the 1994 Agreed Framework.

The United States made a similar calculation when deciding whether to attack China's nuclear weapons program in the early 1960s. Ultimately, the US decided against launching preventative strikes. However, the Kennedy administration seriously considered striking Chinese nuclear reactors at Lopnur and Lanzhou, and even explored a cost-sharing arrangement with the Soviet Union (Chang 1988). The US decision ultimately turned on those factors we identify. Initially, Kennedy ranked the prospect of China acquiring nuclear weapons among the gravest of US security concerns, calling it "intolerable" (Burr and

Richelson 2000/01, 96). The Kennedy administration ordered reports to determine the extent of China's threat to the US and the costs of preventative strikes. Both the Kennedy and Johnson administrations stepped up intelligence gathering efforts and weighed the available evidence prior to China's first test of a nuclear device in 1964. There was widespread agreement that the US would suffer psychological and political costs if China armed. In particular, China would increase its regional influence at the cost of US influence and would gain bargaining leverage with other countries. Leaders in the US also worried nuclear weapons in China might encourage India and Japan to counter with nuclear programs of their own, but they estimated such problems could be offset by increasing US assurances to their allies in the region (p. 77). Moreover, analysts believed that the direct military threat to US security interests was low because of the asymmetry between the US and China's military capabilities. Consequently, the revised bottom line assessment concluded that China having nuclear weapons would be a set-back but not intolerable (p. 97).

At the same time, the US goverment determined that the costs of a preventative action against China were high – too high, in fact, unless they could share costs with interested partners. Costs of a military strike included the complexity of an air attack deep into China, the infeasibility of a ground attack, and the compounding problem of uncertainty about the location of all of China's nuclear locations. Add to this the potential opprobrium of the international community and the possibility of Chinese retaliation against allies. To reduce the costs of preventative strikes, the US explored the possibility of joint strikes against China with the USSR (Chang 1988; Burr and Richelson 2000/01). Decision-makers in Washington reasoned that partnering with the USSR would reduce its own costs by coordinating military efforts and eliminating international backlash. The USSR rebuffed US overtures, arguing that it believed nuclear weapons would only give China regional psychological and political benefits, neither of which adversely affected the USSR (Burr and Richelson 2000/01, 67-70).

The US also explored the possibility of teaming with the Chinese Nationalists (Burr and Richelson 2000/01, 72). According to the plan, the US would transport Nationalist forces from Taiwan to nuclear targets on the Mainland. However, after careful consideration, Washington calculated it would be impossible to deny US involvement, and, therefore, concluded becoming involved with Chiang Kaishek in an offensive attack on China's mainland did not provide the US a sufficiently high savings in its own costs. Without a way to reduce the downsides of a preventative strike against China, the US decided to live with a nuclear

China.

5 Ambiguous Development and Inducements

We now address the questions of why aspirants sometimes develop nuclear weapons ambiguously and why counter-proliferators sometimes offer inducements to ambiguous aspirants. There are several examples of ambiguous nuclear programs. Israel deliberately maintains ambiguity about its program. North Korea was ambiguous in the two decades prior to demonstrating its capability in its 2006 test of a nuclear device. The current status of Iran's nuclear program bears some similarity to North Korea during the 1990s. Iran has reportedly resumed and suspended its enrichment activites on again and off again since the early 2000s, and refuses to cooperate with the International Atomic Energy Agency to clarify the status of its programs. In 2006, US intelligence estimated Iran would have nuclear weapons capability within 5-10 years (Sagan 2006). Latest US assessments estimate Iran will have weapons grade uranium within one year and the capability of assembling a nuclear weapon within 2-5 years (Sanger 2010). South Africa secretly developed nuclear weapons in the 1980s. Prior to India's nuclear tests in 1998, a debate raged about whether India should abandon two decades of nuclear ambiguity, along with its benefits, in exchange for the power and respect of being a transparent nuclear power (Perkovich 1999, 369). Michael Schrage (2003) claims Saddam Hussein "deliberately created ambiguity regarding the true nature of his regime's weapons programs" to deter his immediate threats (Kurds, Iranians, and Saudis) while simultaneously avoiding the ire of the West. As long as external verification of aspirants' nuclear programs is not possible, counter-proliferators are stuck formulating formulating beliefs based upon best available information.

Baliga and Sjostrom (2008: 1025) refer to nuclear ambiguity as "deterrence by doubt." In their model, ambiguity obtains when aspirants refuse to allow weapons inspections, and they arm with some positive probability. They find that an equilibrium exists in which prospective aspirants will never permit inspections, which reduces incentives to proliferate. Ambiguity can deter aggression if there is a sufficiently high probability that the aspirant is really armed but not so high that it will insist on inspections.

Our model introduces a bargaining move and demonstrates that ambiguous aspirants can gain bargaining concessions from counter-proliferators as inducements for aspirants to submit to verifiable denuclearization. In our model, arming decisions are already unverifiable. We further refer to arming decisions as ambiguous if aspirants arm with mixed strategies. A player's mixed strategy affects its opponents beliefs about which pure strategy it will choose. This yields an intuitive interpretation when thinking about decisions to arm with nuclear weapons. If an aspirant mixes its strategies, then the counter-proliferator is not entirely certain whether the aspirant arms. It believes the aspirant both arms and does not arm with positive probability.

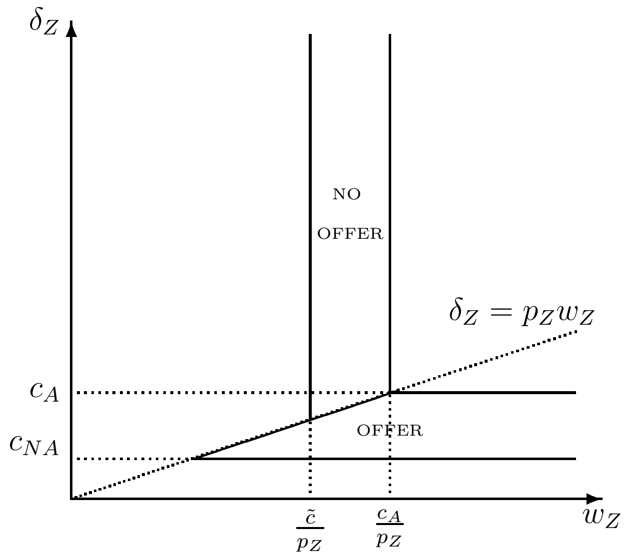

Figure 3: Ambiguity Equilibria.

Our model demonstrates two different sets of circumstances under which aspirants will be ambiguous about arming. First, an aspirant may develop ambiguously to extract concessions from the counter-proliferator. We pointed out above that government A will not offer concessions when B arms with certainty. However, when the aspirant develops ambiguously, offering an inducement to disarm verifiably can be better for the counter-proliferator than fighting a war with a potentially armed aspirant or living with the relatively high worry that the aspirant may be armed and dangerous. The formal conditions for this equilibrium, which we label OFFER in Figure 3, are defined and proved in Proposition 4 in the Appendix. The second possible ambiguity outcome, which we refer to as NO OFFER in Figure 3, occurs when an aspirant expects the counter-proliferator might attack even if there is no chance the counter-proliferator will offer a concession. Corresponding conditions and proofs can be found in Propositions 5 and 7 in the Appendix.

Let us take a closer look at each equilibrium in turn. In the OFFER equilibrium, both types of government B will mix between arming and not arming, and government A

will mix between attacking and providing a concession in the amount of $\delta_Z > 0$. This is the only equilibrium in the model in which A will offer concessions to B, which implies B's ambiguity is critical for extracting concessions. Why is this the case? Suppose the condition $\delta_Z \leq p_Z w_Z$ is violated (see Proposition 4 in the Appendix). Then either a motivated type government B has high utility for arming, in which case A will have to increase the size of its concession to prevent a motivated type from arming with certainty, or the expected threat from a motivated type is low, which makes it more tolerable for A to live with an armed state B. If δ_Z is too high, it is not worthwhile for A to make any concessions at all. Both types would accept δ_Z, but A knows a normal type will accept nothing. Thus, if the expected threat of a motivated type is low (either because it is unlikely B is motivated or A's worry is low), then an offer of δ_Z is suboptimal. In this case, a normal type will not arm with certainty because incurring the cost of investing in nuclear weapons is not worth getting nothing from A in return.

On the other hand, if δ_Z and w_Z are both high, so much so that $\delta_Z \geq c_A$ (thus violating the other condition of Proposition 4), then it is better for A to attack for sure instead of making such a large concession. Because the costs of concessions outweigh the costs of fighting with an armed B, A will attack, and, as we know from Proposition 1, when A attacks in pure strategies, both types of government B will arm. Therefore, regardless of B's true type, being ambiguous about its nuclear program is only an effective bargaining chip if the likelihood of B being a motivated type is sufficiently high, a motivated type's benefits from having weapons are also not too high, and A's costs of striking B are relatively high. Normal type B states can seize on A's belief that B is likely motivated and pool on motivated government's type. Thus, strategic nuclear ambiguity occurs as a result of A both not being able to observe and verify B's action and its inability to distinguish between types in a mixed strategy equilibrium.

In the NO OFFER zone, government B will mix between arming and not arming, and government A will mix between attacking and offering B nothing. This follows when δ_Z is high. Concessions sufficiently high to induce B to abandon its weapons and submit to inspections are too expensive to make to a motivated type, and, therefore, a motivated type will reject any offer it gets. Note that for such high values of δ_Z, government A will live with the threat of an armed motivated government B when its worry w_Z is relatively low (WMD pure strategy equilibrium), which means A ignores B and normal types B are better off not incurring investment costs to arm. On the other hand, government A will attack if w_Z is sufficiently high (WAR pure strategy equilibrium), in which case it is better for normal types B to arm and defend themselves. For intermediate values of w_Z where $\frac{\tilde{c}}{p_Z} \leq w_Z \leq \frac{c_A}{p_Z}$, government A is in between pure strategy equilibria. In this range, B's threat is moderate and the probability that B is a motivated type is relatively low. If A attacks for certain instead of mixing, then even normal types B will arm. Since there is a relatively good chance B is a normal type, then attacking with certainty makes A worse off than attacking with some positive probability. Yet, w_Z is not so low that A can forget about B altogether. Therefore, B mixes between attacking and offering nothing.

As can be seen by the diagonal line in Figure 3, a key distinction between the OFFER and NO OFFER outcomes is the relative values of δ_Z and $p_Z w_Z$. Suppose a counter-proliferator has the same level of worry for two different aspirants, both of whom share the same high probability of being a motivated type. If one of the aspirants values weapons more than the other, then the aspirant with the higher value of weapons could lie above the diagonal line while the other falls below it. The counter-proliferator will not concede an inducement to the aspirant above the line, but will make an offer to the one below. At the same level of worry and probability of being a motivated type, counter-proliferators are more likely to make offers to aspirants with lower values of possessing nuclear weapons. If δ_Z is too high, then it becomes cost-prohibitive for a counter-proliferator to buy off the aspirant.

Now consider a scenario in which two aspirants, both of whom are equally likely to be a motivated type, have the same value for possessing nuclear weapons. One may lie above the diagonal lie and the other beneath if the one beneath causes the counter-proliferator to worry more about the threat of allowing it to possess weapons. When the other parameters are fixed, higher levels of worry can result in a higher likelihood that an ambiguous aspirant gets awarded an inducement from the counter-proliferator.

Israel's policy of deliberate ambiguity about its nuclear program is a good example of a government in the NO OFFER zone, and uncertainty about North Korea's nuclear program prior to its nuclear test in 2006 nicely illustrates the OFFER equilibrium. For most counter-proliferators, especially the United States, Israel has been at least as motivated as North Korea to possess nuclear weapons, but the threat of nuclear weapons in North Korea's hands has always been more worrying. This suggests that a counter-proliferator like the US is more likey to offer inducements for verifiable disarmament to North Korea than Israel. As we discuss below, the US bargained with North Korea in an effort to end its weapons program and allow weapons inspections. By contrast, the US has not done the same with Israel. In fact, in a July 2010 meeting between US President Obama and Israeli Prime Minister Benjamin Netanyahu, Obama seemed to offer support to Israel's nuclear ambiguity, stating that Israel has "unique security requirements."[2] Israel's nuclear ambiguity deters prospective aggressors, since the probability of Israel possessing weapons is itself a deterrent. It also minimizes chances for a regional arms race, which could result if it clarified its capability with a nuclear test. Finally, ambiguity gives Israel the advantage of avoiding international oversight of its nuclear programs, which obligation would follow should it join the NPT. Therefore, having a nuclear ambiguous program meets Israel's security needs, and counter-proliferators like the US, who have relatively low worry about Israel's motivations, do not have an incentive to pay the cost of inducements to get Israel to disarm.

On the other hand, nuclear ambiguity was an effective means for North Korea to extract concessions from counter-proliferators. While we know that North Korea partially detonated a nuclear device in 2006, there was a great deal of uncertainty about its nuclear intentions and the critical details of its enrichment activities during the time period prior to its test. North Korea's path to nuclear weapons was bumpy, and its signals along the way were unpredictable and confusing. It originally resisted joining the NPT, and then finally signed on in 1985. It resisted a safeguards agreement until 1992. It then announced its intention to quit the NPT in 1993, but then agreed to the 1994 Agreed Framework, in which the US offered substantial inducements in exchange for verifiable disarmament. The Agreed Framework collapsed in 2002, and North Korea kicked IAEA inspectors out and withdrew from the NPT. North Korea signed and reneged on other nuclear agreements too, including the 1991 Joint Declaration on the Denuclearization of the Korean Peninsula. Its mixed rhetoric was equally confusing. Sometimes it threatened to unleash a "sea of fire" against the United States, and at other times it has promised cooperation. For example, on September 19, 2005 North Korea agreed to give up its entire nuclear program and the US promised not to attack it. The following day, North Korea announced that it would not give up its nuclear program unless the US provided two light water nuclear reactors. North Korea at various times denied weaponization and, in the next moment, claimed to possess or to be developing weapons (Saunders 2003; Lewis 2010). North Korea's erratic behavior has led scholars to question whether Kim Jung-il might be crazy (Cha and Kang 2003) or psychotic (Coolidge and

Segal 2009). His apparent drive to develop a weapon and unpredictable behavior (neither consistently confirming nor denying having a weapons program) earned him a reputation for being random and caused uncertainty about his nuclear weapons program. Consistent with the predictions of the model, the US met North Korea's ambiguity with offers of concessions.

Scholars and policy-makers have debated about whether North Korea deliberately used its insipient nuclear program as a bargaining chip to exploit concessions from counter-proliferators (Saunders 2003). Historically, its demands have included more than just security guarantees. In fact, compared to contemporary fellow aspirants, who chose to abandon their nuclear weapons programs (e.g., Taiwan and South Korea), North Korea may have had relatively less need to develop a nuclear deterrent (Solingen 2007; Mitchell 2004). Yet, North Korea's program has given it extraordinary leverage to extract concessions from other governments both during the Kim Il-Song and Kim Jong-Il eras. North Korea routinely exported unconventional military technologies in exchange for oil, and made a deal with the Soviet Union in 1985 to sign the NPT in exchange for the Soviet Union giving North Korea a nuclear power plant and increased economic cooperation (Solingen 2007, 129). North Korea still held out on the IAEA safeguards agreement, so the US offered "the withdrawal of US tactical nuclear weapons from South Korea; suspension of the annual US-Republic of Korea military exercise, Team Spirit, in 1992; and a one-time diplomatic exchange with the North in New York in January 1992" (Mazarr 1995, 95). The IAEA discovered inconsistencies with North Korea's program and demanded "special inspections" in 1993. North Korea threatened to withdraw from the NPT, and the US and North Korea cut another deal in the 1994 Agreed Framework which included a US promise not to use nuclear weapons against the North, improve diplomatic relations, two light-water nuclear reactors, and shipments of oil to North Korea in exchange for a freeze on North Korea's weapons program and unimpeded weapons inspections. After that deal fell apart in 2002, North Korea withdrew from the NPT and eventually tested a nuclear weapon. Victor Cha (2009), Director for Asian Affairs at the White House NSC from 2004-2007 and Deputy Chief of the US delegation to the six party talks on North Korea, claimed North Korea's strategy was to gain "energy and economic assistance, normalized relations with the US and a treaty ending the Korean War" as well as an agreement that permits North Korea to retain some nuclear power. Where nuclear disarmament has global currency, it appears that the threat of nuclear weaponization can serve as an effective bargaining instrument.

A comparison with India's nuclear program and the US response is illustrative. India's nuclear weapons program was also ambiguous prior to its test in 1998. While the US was bargaining and cutting deals with North Korea during the early to mid-1990s, the US apparently never offered any inducements to India during the same time period (Perkovich 1999, 345 and 438). The US tried to pressure India not to test a nuclear weapon and signaled its preparedness to accept India's de facto nuclear program as long as the exact status of that program remained unverified (Perkovich 1999, 343). What accounts for the difference in US strategies towards North Korea and India prior to their nuclear tests? The differences can be seen by comparing the equilibria. In both the OFFER and NO OFFER scenarios, the probability the counter-proliferator attacks depends on the values of κ and γ. Government A attacks B with probability $q_A = \kappa/\gamma$, which implies that when B is ambiguous, the likelihood of A attacking increases the higher B's costs of investment in nuclear technology and the lower its benefits from using advanced weapons in a war with A. The lower the costs of investment and higher B's benefits from using advanced weapons, the more likely A will make concessions if it is in the OFFER equilibrium or offer nothing if it is in the NO OFFER equilibrium. By the 1990s, it is safe to assume India's costs of developing weapons were extremely low. US intelligence estimated it already possessed enough "weapon-grade fissile material for twenty to twenty-five nuclear weapons, several of which it could 'assemble within a few days' and deliver by aircraft" (Perkovich 1999, 340). Consequently, the probability the US would actually attack India was also so low as to be a non-factor. However, the US also did not want to offer inducements to India, because it worried relatively little about the threat of India possessing nuclear weapons and India was highly motivated to possess weapons. In this respect, India and Israel are similar cases. By contrast, as we have seen, the US gave serious consideration to attacking North Korea, but instead offered inducements.

Why did the US offer nothing to India instead of offering it some positive inducement, and why did the US offer inducements to North Korea instead of just ignoring North Korea? India fits the NO OFFER equilibrium well. Like Israel, it stood to benefit a great deal from having weapons, because of the combination of threats from neighbors China and Pakistan. In India's case, it was also strongly motivated by nationalistic motivations to be on par with other nuclear states. Consequently, it had high δ_Z – so high that it was more cost efficient for the US to attempt to freeze India's program than to try to roll it back with inducements. It also was less of a threat to the US than North Korea (lower w_Z). On the other hand, North Korea fits the OFFER equilibrium: the US was relatively worried about North Korea (higher w_Z), perceived that North Korea would accept an inducement, and found inducements to be cost-efficient because North Korea was not as motivated as India to keep nuclear weapons (δ_Z not too high).

6 Discussion

In this chapter, we develop a two-person bargaining model to understand why states develop nuclear weapons and why they sometimes do so ambiguously. We also analyze the model to understand when counter-proliferators will use preventative strikes versus inducements to prevent and disable insipient nuclear weapons programs. The results of the model show that a nuclear security dilemma is in play: aspirants arm when they think they are going to be attacked or when their benefits for possessing nuclear weapons outweigh the costs of development regardless of whether they face any serious security threats, and counter-proliferators attack aspirants when they believe aspirants are motivated types, their level of threat from an armed motivated type is high, and their costs for attacking the aspirant is relatively low.

We also show that ambiguous development can be an effective policy for extracting concessions from concerned counter-proliferators. Whether counter-proliferators offer inducements depend on how much motivated types want to keep nuclear weapons. In equilibrium, the probability counter-proliferators offer inducements depends on the costs to the aspirant of investing in weapons relative to its benefits of having weapons in a war. The less expensive aspirants' investment costs, the more likely counter-proliferator will make concessions to it. However, strategic ambiguity is not an effective strategy for gaining concessions when the benefit to the aspirant of acquiring weapons is high. When this is the case, then counter-proliferators may attack with certainty, offer nothing, or mix between these options depending on how much it worries about the aspirant's weapons threat.

The bargaining model we have developed is a useful baseline model to begin thinking about bargaining over nuclear weapons. The model can be extended in many different directions to advance our theoretical understanding of different aspects of nuclear bargaining. One promising direction would be to study the effects of verifiable arming on proliferation and counter-proliferation. In the current model, the counter-proliferator cannot observe B's move to arm, because there are no weapons inspections or other verification mechanisms. The model could be extended to include actions which are verifiable either because the aspirant permits weapons inspections or because it tests a nuclear weapon. The model could also be extended to evaluate the inclusion of sanctions as a possible counter-proliferation strategy. Sanctions accompany many decisions targeting nuclear aspirants, yet little is known about the reasons or effectiveness for such strategies. Other promising avenues include analyzing multilateral bargaining. North Korea preferred bilateral talks while the US preferred six-party talks. What affects governments decisions to press for different negotiation environments? Also, how does uncertainty about the counter-proliferator's preferences affect bargaining? Finally, are democracies more vulnerable to making concessions in nuclear bargaining than autocracies because democratic audiences have higher worry?

7 Appendix

Proof of Proposition 1. We now verify each of these three possible pure strategy equilibria.

1. Because A attacks, it is optimal for both types to arm due to $\gamma > \kappa \Rightarrow \gamma - \kappa - \beta > -\beta$. It is straightforward that under the two inequality conditions of (1),

$$1 - c_A \geq \max\{1 - p_Z w_Z, 1 - \delta_Z\},$$

which implies that it is also optimal for A to attack.

2. If neither type arms, it is optimal for A not to attack and not to offer anything because unarmed B accepts any $x \geq 0$. Note that both types prefer not to arm because of the high cost of investing in WMD, $\delta_N < \delta_Z \leq \kappa$.

3. Given A's strategy, it is optimal for the motivated type to arm when $\delta_Z > \kappa$ by (2). The normal type does not arm due to $\kappa > 0 = \delta_N$. On the other hand, the two inequalities in (2) imply that

$$1 - p_z w_Z \geq \max\{p_z(1 - c_A) + p_N(1 - c_{NA}), 1 - \delta_Z\},$$

which means that A should offer $x = 0$, not attack, and not offer $\delta_Z > 0$. ■

Observe that

$$\tilde{c} = p_Z c_A + p_N c_{NA} \in (c_{NA}, c_A) \Rightarrow \frac{c_{NA}}{p_Z} < \frac{\tilde{c}}{p_Z} < \frac{c_A}{p_Z}$$

$$\tilde{c} = p_Z c_A + p_N c_{NA} < p_Z c_A \Rightarrow c_A < \frac{\tilde{c}}{p_Z}$$

Two Remarks:

1. When $\kappa > c_A$, WAR and PEACE may coexist, as illustrated above.
2. When $\kappa \leq c_A$, these three types of equilibria generally do not coexist (except on a set of measure zero).

Now we argue that there is no other pure strategy equilibrium.

- If the normal type arms but the motivated type does not, then country A would still offer $x = 0$. Then the normal type will not arm.
- If both types arm and A offers 0, then the normal type will prefer not to arm.
- If both types arm and A offers δ_Z, then both types will accept and will not arm (this is also the case even if A knows that B is motivated.)

1. If A attacks, A's payoff will be

$$\begin{aligned} & (p_Z\pi_Z + p_N\pi_N)(1 - c_A) + (1 - p_Z\pi_Z - p_N\pi_N)(1 - c_{NA}) \\ &= 1 - \left[\underbrace{(p_Z\pi_Z + p_N\pi_N)\, c_A + (1 - p_Z\pi_Z - p_N\pi_N)c_{NA}}_{=\bar{c}}\right] = 1 - \bar{c}. \end{aligned}$$

2. If A offers $x \in [0, \delta_Z) = [\delta_N, \delta_Z)$, only armed motivated type rejects and hence A's payoff is

$$p_Z\pi_Z(1 - w_Z) + (1 - p_Z\pi_Z)(1 - x) \leq p_Z\pi_Z(1 - w_Z) + (1 - p_Z\pi_Z) = 1 - p_Z\pi_Z w_Z,$$

   which implies that offering any $x \in (0, \delta_Z)$ is dominated by offering $x = \delta_N = 0$.

3. If A offers $x \geq \delta_Z$, B will accept and hence A's payoff is $1 - x \leq 1 - \delta_Z$, which implies that offering any $x > \delta_Z$ is dominated by offering $x = \delta_Z$.

In equilibrium a strategy of ambiguity is represented as a mixed strategy in which B arms with some probability π and does not arm with probability $1 - \pi$, and A does not get to observe which action was taken. Government A will make concessions with some positive probability which depends on B's costs and benefits of arming.

First notice that during the last stage of the game where B's information set is a singleton, armed type t accepts A's offer if and only if $x \geq \delta_t$ and unarmed type t accepts any offer $x = 0$. Also observe that if A plays a pure strategy/action, then both types of B will play pure strategies as well. In other words, in any mixed strategy equilibrium, A must play a mixed strategy. There are four nodes in A's information set. Let π_Z be the probability that the motivated type is armed, and π_N be the probability that the normal type is armed.

To summarize, we obtain the following lemma:

Lemma 2 *In any mixed strategy equilibrium, A must mix among the following three actions from which A has the same expected payoff:*

A's action	*A's expected payoff*
attack	$1 - (p_Z\pi_Z + p_N\pi_N)\, c_A + (1 - p_Z\pi_Z - p_N\pi_N)c_{NA}$
offer $x = 0$	$1 - p_Z\pi_Z w_Z$
offer $x = \delta_Z$	$1 - \delta_Z$

At this point, we cannot exclude any of these three actions. Unlike in any pure strategy equilibrium, we cannot exclude the possibility that A offers δ_Z to B.

Now we turn our attention to B's strategies. Suppose that A attacks with probability q_A, offers $x = 0$ with probability q_0, and offers $x = \delta_Z$ with probability $q_1 = 1 - q_A - q_0$

Lemma 3 *In any mixed strategy equilibrium,*

(i) if $q_0 > 0$ and the normal type mixes, then the motivated type will arm.

(ii) if $q_0 = 0$ and the normal type mixes, then the motivated may also mix.

Proof. If the normal type mixes, then we have

$$q_A\,(\gamma - \beta) + q_1\delta_Z - \kappa = q_A\,(-\beta) + q_1\delta_Z \Leftrightarrow \frac{\kappa}{\gamma} \in (0, 1).$$

The motivated type has a higher payoff from being armed if $q_0 > 0$:

$$q_A\,(\gamma - \beta) + q_0\delta_Z + q_1\delta_Z - \kappa > q_A\,(-\beta) + q_1\delta_Z.$$

In other words, if $\pi_N > 0$ and $q_0 > 0$ then $\pi_Z = 1$. ■

Proposition 4 *If $c_{NA} \leq \delta_Z \leq c_A$ and $\delta_Z \leq p_Z w_Z$, there is the following mixed strategy equilibrium:*

- *Type t arms with probability $\pi_t \in [0,1]$ such that*

$$p_Z\pi_Z + p_N\pi_N = \frac{\delta_Z - c_{NA}}{c_A - c_{NA}} \quad \textit{and} \quad \pi_Z \geq \frac{\delta_Z}{p_Z w_Z}, \tag{3}$$

- *Country A attacks with probability $q_A = \kappa/\gamma$ and offers δ_Z with $q_1 = 1 - \kappa/\gamma$.*

  The expected payoff of country B (of either type) is

$$q_A(-\beta) + (1 - q_A)\delta_Z = \delta_Z - \frac{\kappa}{\gamma}(\delta_Z + \beta),$$

  and country A's expected payoff is $1 - \delta_Z$.

Proof. Suppose that A attacks with probability $q_A = \kappa/\gamma$, and does not offer $x = 0$. Then A must offer $x = \delta_Z$ with probability $q_1 = 1 - q_A = 1 - \kappa/\gamma$.

Since A does not offer $x = 0$, both types have the same payoffs from being armed and not armed. A is willing to mix iff it receives the same expected payoff from attacking and offering $x = \delta_Z$, which is determined by $q = p_Z\pi_Z + p_N\pi_N$ (the probability that B is armed) by the following equation:

$$q(1 - c_A) + (1 - q)(1 - c_{NA}) = 1 - \delta_Z$$
$$\Rightarrow q^* = \frac{\delta_Z - c_{NA}}{c_A - c_{NA}} \in [0,1] \text{ iff } c_{NA} \leq \delta_Z \leq c_A.$$

For all $p_Z + p_N = 1$, there are $(\pi_Z, \pi_N) \in [0,1]^2$ such that

$$p_Z\pi_Z + p_N\pi_N = \frac{\delta_Z - c_{NA}}{c_A - c_{NA}} \in [0,1].$$

On the other hand, country A does not offer $x = 0$ iff

$$1 - \delta_Z \geq 1 - p_Z\pi_Z w_Z \Leftrightarrow \pi_Z \geq \frac{\delta_Z}{p_Z w_Z}.$$

The above inequality implies

$$\frac{\delta_Z}{p_Z w_Z} \leq 1 \Leftrightarrow \delta_Z \leq p_Z w_Z.$$

Observe that the conditions $c_{NA} \leq \delta_Z \leq c_A$ and $\delta_Z \leq p_Z w_Z$ ensure the existence of well-defined mixed strategies $(\pi_Z, \pi_N) \in [0,1]^2$ that satisfy the two conditions in (3). ■

The mixed strategy equilibrium in Proposition 4 is our "interesting" ambiguity equilibrium because A will make concessions with positive probability. We describe it in greater detail below. For now, we assign values to our parameters to illustrate an example of this mixed strategy equilibrium. Suppose that $c_A = 0.3$, $c_{NA} = 0.1$, $p_Z = p_N = 0.5$, then

$$\begin{aligned} c_{NA} &\leq \delta_Z \leq c_A \Leftrightarrow 0.1 \leq \delta_Z \leq 0.3 \\ \delta_Z &\leq p_Z w_Z \Leftrightarrow \delta_Z \leq 0.5 w_Z. \end{aligned}$$

We now move to another mixed strategy equilibrium. This time A does not offer concessions in equilibrium. Suppose that $\pi_N > 0$ and $\pi_Z = 1$. In order for A to mix, we need

$$(p_Z + p_N \pi_N)\, c_A + (1 - p_Z - p_N \pi_N) c_{NA} = \min\{p_Z w_Z, \delta_Z\}.$$

We can state the following proposition:

Proposition 5 *If* $\delta_Z \geq p_Z w_Z$ *and*

$$\frac{\tilde{c}}{p_Z} \leq w_Z \leq \frac{c_A}{p_Z}, \tag{4}$$

there is a mixed strategy equilibrium in which the motivated type arms and the normal type arms with probability π_N *where*

$$(p_Z + p_N \pi_N)\, c_A + p_N (1 - \pi_N) c_{NA} = p_Z w_Z. \tag{5}$$

A attacks with probability $q_A = \kappa/\gamma \in (0, 1)$, *offers* $x = 0$ *with with probability*

$$\begin{cases} q_0 = 1 - q_A & \text{if } \delta_Z > p_Z w_Z \\ q_0 \in (0, 1 - q_A] & \text{if } \delta_Z = p_Z w_Z \end{cases}.$$

Country A's payoff is $1 - p_z w_z$, *normal type B's payoff is* $-\beta\kappa/\gamma$, *motivated type B's payoff is*

$$\frac{\kappa}{\gamma}(\gamma - \beta) + \left(1 - \frac{\kappa}{\gamma}\right) \delta_2 - \kappa = \delta_2 - \frac{\kappa}{\gamma} (\delta_2 + \beta)\,.$$

Proof. First observe that if $q_A = \kappa/\gamma$, the normal type is indifferent between arm and not arm. Lemma 3 implies that it is optimal for the motivated type to arm when $q_0 > 0$.

Given B's strategies, (5) states that A has the same expected payoff to attack or to offer $x = 0$. Solving (5) yields

$$\pi_N = \frac{p_Z w_Z - c_A p_Z - p_N c_{AN}}{p_N (c_A - c_{AN})} \in [0, 1] \quad \text{by (4)}.$$

To conclude, note that when $p_Z w_Z = \delta_Z$, A may mix between offering $x = 0$ and $x = \delta_Z$ arbitrarily. However, if A only mixes between attack and offering δ_Z, then the equilibrium is the same as the one characterized in Proposition 4. ■

The conditions in Proposition 5 describe a set of (w_Z, δ_Z) above line $\delta_Z = p_Z w_Z$. Except a measure-zero set, the last two propositions are mutually exclusive.

Consider the following example. Suppose that $c_A = 0.3$, $c_{NA} = 0.1$, $p_Z = p_N = 0.5$, then

$$\begin{aligned} \delta_Z &\geq p_Z w_Z \Leftrightarrow \delta_Z \geq 0.5 w_Z \\ \frac{\tilde{c}}{p_Z} &\leq w_Z \leq \frac{c_A}{p_Z} \Leftrightarrow 0.4 \leq w_Z \leq 0.6. \end{aligned}$$

Lemma 6 *In any mixed strategy equilibrium,*

(i) if $q_0 > 0$ and the motivated type mixes, then the normal type will not arm.

(ii) if $q_0 = 0$ and the motivated type mixes, then the normal type may also mix.

Proof. Suppose that A attacks with probability q_A, offers $x = 0$ with probability q_0, and offers $x = \delta_Z$ with probability $q_1 = 1 - q_A - q_0$. If the motivated type mixes, then

$$q_A (\gamma - \beta) + q_0 \delta_Z + q_1 \delta_Z - \kappa = q_A (-\beta) + q_1 \delta_Z \Leftrightarrow q_A = \frac{\kappa}{\gamma}.$$

Because $\delta_Z > \delta_N = 0$, the normal type has higher payoff from not being armed if and only if $q_0 = 0$:

$$q_A (\gamma - \beta) + q_1 \delta_Z - \kappa < q_A (-\beta) + q_1 \delta_Z.$$

Note that (ii) is the same as (ii) of Lemma 3. ■

Lemmas 3 and 6 assert that in any mixed strategy equilibrium, A must attack with probability $q_A = \frac{\kappa}{\gamma}$. This implies that if $\kappa \geq \gamma$, then there is no mixed strategy equilibrium.

Next, we focus on the possibility of a mixed strategy equilibrium where the motivated type mixes and the normal type does not arm, and A mixes between attack and offer $x = 0$ with $q_0 > 0$.

Proposition 7 *If there exists $\pi_Z \in [0, 1]$ such that*

$$p_Z \pi_Z c_A + (1 - p_Z \pi_Z) c_{NA} = p_Z \pi_Z w_Z = \min\{p_Z \pi_Z w_Z, \delta_Z\}, \tag{6}$$

there is a mixed strategy equilibrium where the normal type does not arm, the motivated type arms with probability π_Z*, A attacks with probability* $q_A = \kappa/\gamma \in (0,1)$*, and offers* $x = 0$ *with probability*

$$\begin{cases} q_0 = 1 - q_A > 0 & \text{if } \delta_Z > p_Z \pi_Z w_Z \\ q_0 > 0 & \text{if } \delta_Z = p_Z \pi_Z w_Z \end{cases}$$

(if $p_Z \pi_Z w_Z = \delta_Z$*, country A may mix between offering* $x = 0$ *and* $x = \delta_Z$ *arbitrarily).*

Normal type B' payoff is $q_A(-\beta) = -\beta\kappa/\gamma$*, motivated type B's payoff is*

$$\frac{\kappa}{\gamma}(-\beta) + \left(1 - \frac{\kappa}{\gamma}\right)\delta_Z = \delta_Z - \frac{\kappa}{\gamma}(\delta_Z + \beta)$$

Country A's payoff is $1 - p_z \pi_Z w_z$*.*

Proof. It is straightforward to verify such a mixed strategy equilibrium. Now we validate condition (6). Note that (6) implies that

$$\pi_Z = \frac{c_{NA}}{p_Z(w_Z + c_{NA} - c_A)} \in [0,1] \Leftrightarrow w_Z \geq \frac{\tilde{c}}{p_Z}.$$

Also, $p_Z \pi_Z w_Z = \min\{p_Z \pi_Z w_Z, \delta_Z\}$ requires that

$$\delta_Z \geq p_Z w_Z \pi_Z = \frac{c_{NA} w_Z}{w_Z + c_{NA} - c_A} = \frac{c_{NA}}{1 + \frac{c_A - c_{NA}}{w_Z}} \in (0, c_{NA})$$

which is an increasing function of w_Z. ■

To illustrate, suppose that $c_A = 0.3$, $c_{NA} = 0.1$, $p_Z = 0.5$, then $w_Z \geq \frac{\tilde{c}}{p_Z} = 0.4$. The other condition is

$$\delta_Z \geq \frac{c_{NA} w_Z}{w_Z + c_{NA} - c_A} = \frac{0.1 w_Z}{w_Z + 0.2}.$$

Notes

[1]Examples of such efforts include the Nuclear Threat Initiative, which focuses on securing and reducing the spread of nuclear matarials and technology, and the Harvard Belfer Center Project on Managing the Atom, which emphasizes the management and protection of fissile material. See, for example, Bunn 2010.

[2]This meeting was widely reported in the press. A statement given by Assistant Secretary of State Andrew J. Shapiro addressing Obama's comments and the Obama administration's policy toward Israel can be found on the US Department of State webpage. See Shapiro 2010.

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