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Shadow Wars of Weapons Acquisition:

Arms Denial and its Strategic Implications

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Abstract

In trying to prevent adversaries from acquiring new military capabilities, countries often employ strategies of *arms denial;* e.g., “unilateral diplomacy,” supply chain interdiction, covert sabotage and targeted military strikes. We posit that the prevalence of this approach gives rise to strategic effects that affect all players’ behavior. We explore this phenomenon using a game-theoretic model of weapons acquisition and denial. Our model shows that denial could indeed be the equilibrium result of such strategic interactions, and provides the conditions under which the *threat* of denial is sufficient to cause adversaries to refrain from acquisition altogether. We further identify strategic levers that actors can use to improve their position in this interaction. The results of the model are illustrated using real-world examples and are then used to assess the implications of arms denial on arms races and regional stability.

1. Introduction

The acquisition of highly expensive and technically sophisticated new military capabilities is a central aspect of modern-era warfare. In the past, the response of adversaries to this acquisition process was mostly limited to a reciprocal effort to acquire ever better capabilities and counter-measures, yielding regional and global arms races. With time, and as technology and its proliferation allow ever increasing capabilities to be acquired by a more diverse set of actors, preventive approaches have been developed aiming to restrict the acquisition process itself.

Most of the current security studies literature focuses on two complementary approaches to prevention: arms control and coercive diplomacy on the one hand, and the use of military force on the other hand. In the diplomatic approach, the preventing actor uses a 'carrots and sticks' strategy to coerce the acquiring actor to sign a bilateral or multilateral arms control agreement (Schelling and Halperin, 1961; George and Simons 1994, Art and Cronin 2003), such as in the Libyan agreement to completely dismantle its nuclear program in 2003. This approach ultimately hinges on the acquiescence of the acquiring actor to cease its acquisition process. In the purely military approach, a preventive war is waged in order to completely remove the potential threat, such as in the case of the war against Iraq in 2003.

Preventing actors, however, also engage in a third approach– *Arms Denial* (Carter, 2004), whereby the capability acquisition process is prevented, or delayed, using a variety of non-cooperative diplomatic, clandestine, or other military actions that are short of war. Recent attempts of arms denial include recurring pressure on the Russian government to refrain from selling the S-300 surface-to-air missile system to Iran (Kessler and Richburg, 2010), the use of the Stuxnet cyber-weapon to cripple Iran's nuclear program (Sanger, 2012), and an air strike against a nuclear reactor in Syria (Sanger and Mazzetti, 2007), to name just a few well-known examples.

The objective of this paper is to analyze the resulting strategic behavior of participants in these acquisition and denial interactions. We show that the use of arms denial has become prevalent, resulting from a concurrent increase in the need for arms denial and in the capabilities to carry it out, to the degree that it has a long-run strategic effect on the considerations of all sides involved. To further explore this effect, we develop a game-theoretic model with three stages, accounting for one actor's choice to acquire a new capability (hereafter acquiring actor), another actor's decision to deny that capability (hereafter denying actor), and the acquiring actor's option of recovery. The model allows for the success of denial to be uncertain, the cost of recovery to be different than the cost of acquisition, and the value of the acquired system to change over time.

We show that arms denial can be divided into two categories: *preventive* arms denial – where the target's recovery following successful denial is not cost-effective; and *disruptive* arms denial, where it is optimal for the acquiring actor to invest in recovery if denial succeeds. We find that both outcomes are prevalent, but for different reasons. In the case of *preventive* arms denial, if the acquiring actor perceives the probability of successful denial to be low enough, it could warrant an acquisition attempt, which would then be followed by a denial attempt. In contrast, in the case of *disruptive* arms denial, while the denying actor foresees the acquiring actor's recovery effort, it may still attempt denial in order to "buy" time for developing counter-measures or facilitating negotiated solution.

In addition, we show that when denial is valuable, its success is highly probable, and recovery is costly, the implicit threat of denial causes the first actor to refrain from acquisition altogether (in some cases even when recovery would have been optimal *ex post*). For concreteness, we illustrate each of these equilibrium strategies using examples from the Iranian, Iraqi and Syrian nuclear programs.

Denying and acquiring actors typically strive to change each other's cost-effectiveness calculus to their benefit. Our analysis offers *strategic levers* that actors can use to strategically change the equilibrium outcome of the game, explaining many phenomena seen in the real world such as an acquiring actor's use of covert and underground facilities, civilian façade of potentially-military programs or the trend towards technical self-reliance. In contrast, a denying actor is could set up dedicated denial organizations, put more emphasis on development of defensive systems and frequently use non-attributable denial methods.

The model builds on previous work on rationalist explanations for the use of force in preventing new military capabilities (Fearon, 1995; Powel, 2006; Slantchev, 2011; Bass and Coe, 2012; Debs and Monteiro, 2014). In particular, our model bears similarity to a recent paper by Debs and Monteiro (2014), who also endogenize the decision to acquire a new military capability. Their focus, however, is on the effect of informational asymmetries on decisions of acquisition and the use of military force to prevent it. Our model abstracts away from informational asymmetries, but rather expands on the role of (shared) uncertainties and on the impact of changes in costs and benefits which are inherent to arms denial.

Also closely related to our research is Bas and Coe (2014), which explores the effect of uncertainty and intelligence gathering on acquisition and preventive wars. In their model, the game ends after a preventive war, and recovery is not possible. Our model, in contrast, looks at arms denial, where recovery is a potential choice for the acquiring actor. This, in turn, affects the strategic considerations of both actors, yielding different results.

The rest of the paper is organized as follows. The next section elaborates on the concept of arms denial and provides further evidence for its prevalence. This is followed by a description of the model and its outcomes. The latter are then demonstrated using vignettes of recent events. We conclude with policy recommendations and directions for future research.

2. Arms Denial

The concept of arms denial as an intermediate strategy between diplomacy and war is not new, both operationally (dating back at least to the beginning of the Cold War[2]) and conceptually – Carter (2004) defines it as one of the "8-Ds" of counter-proliferation. Setting aside the more "defensive" types of denial (e.g., export controls on sensitive technologies or security measures for sensitive material such as fissile material), there is little discussion of arms denial in the existing literature, particularly on the strategic implications arms denial might have on acquisition decisions. We use the term *acquisition* throughout the paper to include both indigenous development and foreign procurement of weapon systems.

This lack of scholarly attention could be explained by the clandestine and often benign aspects of denial, leading to only a few prominent cases to actually reach wide public awareness. Even then, such events are typically considered as either idiosyncratic or analyzed according to the operational method that is used. As a result, targeted strikes such as those on the Iraqi reactor in 1981 and the Syrian reactor in 2007, for example, are seen as related to the preventive war against Iraq in 2003, because military force is used in all cases. Another example is the Stuxnet cyber-attack on Iran's nuclear program, which is often analyzed with other cyber-attacks such as the cases of Estonia in 2007 and Georgia in 2008 (Kello, 2013), as part of a broader discussion of cyber as a war-fighting domain. In contrast, looking at these cases from the point of view of both the acquiring actor and the denying actor, the underlying logic of these three events is similar in that they are aimed at, and limited to, denial of the acquisition of a new military capability.

[2] There are cases dating back to World War II (such as the Allied forces' attempts to prevent a German nuclear weapon), but we consider intra-war denial to be a different case, as these are done in a different environment and with a different logic and constraints than peacetime denial.

A broad spectrum of operational methods falls within the scope of *arms denial*: The most subtle is *"unilateral diplomacy,"* where denying actors strive to dissuade a third party from selling or allowing the export of certain systems (weapons, equipment, components, etc.) to the acquiring actor. Examples include the Russian S-300 missiles mentioned earlier and Chinese pressure on the US to refrain from selling advanced fighter jets and other weapon systems to Taiwan (Landler, 2011). Less subtle is the *interdiction* of systems en-route to the target actor. Interdiction is used much more frequently since the 2003 instigation of the Proliferations Security Initiative (PSI)—a US-initiated multinational effort trying to stop the proliferation of technologies related to nuclear, chemical and biological weapons and their delivery systems, by broadening the set of acceptable measures member countries may employ (PSI, 2014). Next in order of aggressiveness is the use of covert capabilities, such as clandestine forces, cover companies, foreign agents, and cyber-weapons, to *sabotage* hardware and software systems, either within the acquiring actor's territory or outside of it (for example, Iran has repeatedly accused the West of selling it faulty equipment to sabotage its nuclear program; see Hunt, 2014). Finally, a targeted military strike could be used to *physically destroy* the target system or related facilities, as in the aforementioned examples of Iraq and Syria. The use of these diverse operational methods is not mutually exclusive, and in some cases multiple methods have indeed been used; for example in countering Iran's nuclear program (Sanger, 2012, pp. 141-242).

A key characteristic of arms denial interactions is that following denial by one side, the other side often attempts to *recover* and succeed in acquiring the desired new capability. Given that arms denial does not change the underlying strategic situation of the acquiring actor, the question of recovery rests mostly on its cost-effectiveness for the acquiring actor. The cost and the benefit of the acquired capability may very well change following a denial attempt. The cost of recovery depends on the nature of the challenge posed by denial, and could be quite high. In the case of the Iraqi nuclear program for example, following the Israeli strike on the Osiraq reactor in1981, Iraq's choice of recovering by a covert enrichment program significantly increased the cost of the program. According to Reiter (2005, p. 362), “The Iraqi nuclear program increased from a program of 400 scientists and $400 million to one of 7,000 scientists and $10 billion.”

Since the effort of recovery might significantly delay the acquisition process and the success of recovery is not guaranteed, the expected benefit (or value) of the acquired system may also change following denial. The effect of time delay on the value of the acquired system could be considerable to both actors for several reasons. In general, it is better for the denying actor that the threat materializes later rather than sooner (similar to the standard logic of a “discount rate”). Naturally, the opposite holds for the acquiring actor. Denial attempts may increase over time the perceived value of a given system in the acquiring state (similar to the logic of an appreciation rate). Added time allows the denying actor to develop additional alternatives for denial which can then be used to further delay the acquisition process or to coerce the acquiring actor to forfeit the acquisition effort. In addition, in parallel to denial efforts, the denying actor could start developing various counter-measures and defensive measures that would erode the operational significance of the acquired capability once it is obtained. For example, missile defense capabilities could be developed to counter the effectiveness of missiles. The longer the denying actor has to develop such defensive measures, the lower the net value the acquiring actor receives from the new capability. Furthermore, external future changes might make the capability irrelevant or undesired to the acquiring actor. For example, even if Syria continued its nuclear program following the destruction of its reactor in 2007, such an effort would have probably been halted following the 2011 revolution attempt and ensuing civil war. Finally, as the challenge posed by denial could be operationally and technically significant, recovery is not guaranteed to succeed, thus lowering the *a priori* expected benefit of recovery.

Despite the prospect of recovery by the acquiring actor, the occurrence of arms denial is remarkably prevalent. Table 1 provides a distribution, by denial methods, of known arms denial events in the decade between 2004 and 2013. Overall, there were (at least) 31 reported arms denial *events* during this period, which could be classified into 10 arms denial *cases* (defining a "case" to be the denial of a certain system attempted to be acquired by a certain actor; e.g., Iran's nuclear program is regarded as one such *case*). Table 2 shows the distribution of cases by types of acquiring actor (state / non-state actor) and target system (nuclear weapon or delivery systems / conventional weapon systems).

Table 1: Arms Denial Events by Method

Method	Diplomacy	Interdiction	Sabotage	Military strike	Total
Number of events	3	11	9	8	31

Table 2: Arms Denial Cases by Types of Acquiring Actor and Target System

Acquiring Actor Type / Target System	State	Non-State actor
WMD / Delivery system	**2**	**4**
Conventional weapons	**4**	**--**

Note that the above number of reported arms denial events is a lower limit on the actual number of events, for two reasons: First, not all arms denial attempts are publicly reported by either side; thus, additional events may have occurred during this period of time and have not been disclosed. Second, the distinction between a denial attempt and an accident is sometimes ambiguous, as some arms denial events could be perceived as resulting from accidents, misfortune or incompetence, and conversely accidents are sometimes interpreted as arms denial by the media (for example, an explosion that reportedly destroyed an Iranian missile base in 2011 has been described alternatively as an accident or as an act of sabotage, see Sanger and Broad, 2011). Our data include only events that were formally described as arms denial by the denying actor, the acquiring actor or a credible third party (UN, IAEA, etc.).

The tables above present events only since 2004 and thus do not provide a complete historical overview of arms denial. Nevertheless, a cursory look at the last decades' events suggests an increase in frequency of arms denial events over this period of time (for example, a review of the period 1980-1990 yielded 3 arms denial event, classified into 2 cases). While it is possible that the actual number of events did not actually change but rather the availability of information in the last decade made such events become more public, we believe that this upsurge is in fact driven by several important changes in the underlying need for arms denial and in the capability to carry it out. First, the progress of technology allows a broader set of countries and non-state organizations to obtain advanced military capabilities, thus increasing the value of prevention for their adversaries. Second, the increased importance of non-state actors has rendered the alternatives of negotiated multilateral agreements (i.e., arms control) or threats of preventive wars less viable than before. Third, the collapse of the Soviet Union has transformed the arms sales market from one based on patron-client relationships along the US/Soviet lines to a more diverse market with multiple suppliers. This change has decreased the political costs of arms denial (which would have been very risky against the Soviet Union) and created additional points of intervention due to the more dispersed and international nature of the current arms market (For example, maritime delivery of goods often involves transshipment in ports other than the ports of origin and destination). Finally, developments in the fields of accurate real-time intelligence (reconnaissance satellites and drones, cyber espionage), stand-off precision strike and cyber-weapons allow arms denial to be exercised in cases where information gaps and potential for collateral damage might have precluded it in the past.

The frequent occurrence of arms denial events raises several important questions on their operational and strategic effects. Our paper focuses on the latter. While there is no consensus in the literature on the operational effectiveness of arms denial methods (e.g., Vielhaber and Bleek, 2012; Malin, 2013), their continued implementation implies that they are at least perceived as effective by the denying actors. That, in turn, leads to the key questions about this strategic interaction: how does an actor contemplating the acquisition of a new capability address the apparent potential of future denial? Can denial be used to deter actors from initiating an acquisition attempt of certain capabilities? To address these questions, we develop below a stylized strategic model of acquisition, denial, and recovery decisions.

3. Model Setup

The model considers the interactive decision making of two rational, unitary, risk-neutral actors: an acquiring actor *A*, who considers the acquisition of a new military capability, and a denying actor *D*, who in turn contemplates interfering with the acquisition process thus denying *A* of this capability.

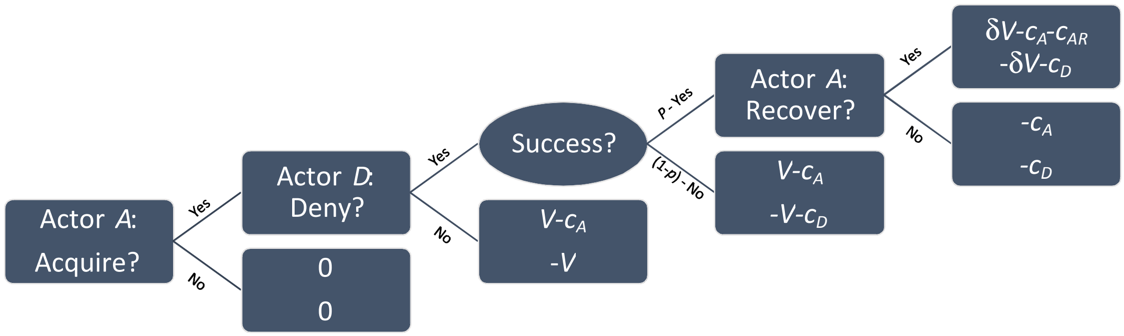

Figure 1: Description of the model

The model proceeds in three stages (see figure 1). In the first stage, *A* decides whether to spend its resources on a new military capability. The cost of acquisition is C_A, and if successful, would provide *A* with a positive value *V*. The value of the system could be seen as the 'shift of power' that would follow the acquisition of this new capability.[3] We think of the cost of acquisition in a broad way incorporating in addition to the actual costs of the resources required to obtain this capability (i.e., technology, equipment, personnel, etc.), and the more abstract costs, such as political and economic cost (for example, the costs of future sanctions). We assume that $V > C_A$, otherwise the proposition of acquiring the new military capability is not attractive to begin with, regardless of denial.

In the second stage, *D* decides whether to attempt to obstruct *A*'s acquisition process, thereby, denying *A*'s acquisition of the sought for capability. Denial has an ensuing cost C_D, and a probability of success *p*, which are assumed to be given. The cost of denial is assumed to encompass the multi-dimensional costs of the denial act. These costs include, for example, the actual operational costs of the resources used to

[3] In the context of the literature on rationalist explanations for war, most models employ an explicit bargaining model to determine the allocation of a disputed resource between the two actors. For simplicity, we abstract away from explicit bargaining, and assume that if the new capability is obtained, the shift of resources from the denying actor to the acquiring actor is equal to V. In this case, if the new capability is not obtained, the original allocation is maintained, yielding a zero change for both actors. It can be shown that this simplification does not change the results of the original explicit bargaining model.

implement denial,[4] the alternative costs of using those resources for denial (for example, the potential exposure of intelligence sources), and the political and diplomatic costs of denial (such as international condemnation or potential hostile reaction by *A*). To simplify notation, we assume that the probability of successful denial, *p*, incorporates the probability of successfully blocking *A*'s acquisition process as well as the probability that *D* is in fact aware of *A* pursuing an acquisition process. If D decides not to attempt denial, or if denial fails, *D* faces a negative value of $-V$.[5]

Finally, we assume that denial is not irreversible. Since denial does not impact the underlying "grand-strategy" of *A* (being short of preventive war), if denial succeeds, *A* may choose to recover and reconstitute the acquisition process at a cost C_{AR}. We allow for C_{AR} to be different than the original cost of acquisition, C_A. This assumption implies that a 'recover and reconstitute' choice requires overcoming new difficulties posed by *D*'s denial which may call for modified planning or special design and implementation. The value for *A,* if it chooses to recover, is δV (and $-\delta V$ for *D*), where $\delta<1$. As discussed in the previous section, the erosion of value over time could be significant if one integrates the effect of the standard discount rate, the potential for external changes, the development of alternatives for denial and prevention, the development of defensive systems or other counter-measures, and the probability that recovery may not succeed. As we show below, the erosion of the value of the acquired capability over time is an important driver of the actors' equilibrium behavior.[6]

Finally, we assume all parameters to be common knowledge to both actors, abstracting away from informational asymmetries.

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[4] For simplicity, we assume here that denial is a single act, though it could comprise of several methods as described in the previous section.

[5] Symmetric values are assumed only for ease of presentation. It is straightforward to extend the model to the case where players' values are asymmetric, as long as this valuation is common knowledge. Such asymmetry does not change any of the results qualitatively.

[6] Unlike Debs and Monteiro (2014), we refrain from an explicit modeling of multiple periods. The effect of different delay times can be calculated through the choice of different discount factors. Thus, for example, if the discount factor for a delay of one year is δ_1, and the a denial attempt may delay acquisition for N years, in our model that would be equivalent to $\delta = \delta_1^N$.

4. Equilibrium Analysis

In this section we present the model solution. The implications are discussed and illustrated in the next section. We use a sub-game perfect equilibrium as the solution concept for our game, where a solution is a pair of strategies, one for each actor. We solve by backward induction.

In the third stage, *A* must choose whether to recover or not, given that *D* succeeded with its denial. We define the case where in the third stage *A* discontinues its arms effort "*preventive* arms denial", and call the case where *A* chooses to recover "*disruptive* arms denial". The key parameters governing *A*'s recovery decision are the expected value after recovery, δV, and the cost of recovery, C_{TA}. We first study *preventive* arms denial (i.e., $\delta V < C_{AR}$), and then analyze *disruptive* arms denial—$\delta V > C_{AR}$.

Lemma 1: In the case of preventive arms denial, the expected value of denial equals pV.

Proof: Straightforward.

Proposition 1: For *preventive* arms denial, if the expected value of denial is higher than its costs (i.e., $pV > C_D$), then

a) Denial occurs if $(1-p)V > C_A$, in which case post-denial *A* abandons the acquisition effort.

b) *A* completely refrains from acquisition if $(1-p)V < C_A$

Otherwise, if $pV < C_D$, *A* acquires the new capability uninterrupted.

Proof: all proofs are in the appendix.

For *D*, this is a relatively simple decision: if the expected value from denial is higher than its costs, *D* attempts denial. *A*'s decision is a bit more subtle. According to Proposition 1 the prospect of preventive arms denial affects *A*'s decision-making in two ways. If *A*'s expected value from a successful acquisition is higher than its acquisition costs (1a), *A* pursues an *Attempt* strategy, in which he takes a calculated risk and chooses to try and acquire the capability. Since $pV>C_D$, *D* attempts denial. Since the preventive denial case assumes recovery to be too costly, $\delta V<C_{AR}$, if denial succeeds *A* abandons the acquisition effort; foregoing any invested sunk costs.

More interestingly, if the probability of successful denial is high enough (1b), such that *A*'s expected value from successful acquisition is smaller than its costs, *A* refrains from acquisition altogether. In this case, *A* presumes the probability of successful denial to be too high and recovery to be too costly relative to the expected value from the acquired capability. We refer to this case as a R*estraint* strategy. Assuming that *A* behaves rationally and does not pursue the acquisition effort, denial does not actually occur. That is, under *Restraint*, the prospect of denial has a strategic effect: it poses an implicit credible threat which in turn deters *A* from making any acquisition efforts. In the opposite case, if $pV<C_D$, the expected value of denial (taking into account its uncertain success) is lower than its costs resulting in an uninterrupted acquisition strategy.

By definition, in the case of preventive arms denial, *A* chooses not to continue acquisition after a successful denial. Consequently, in this case, the erosion of value because of delay (hereafter, the value of delay) does not affect the players' decisions. The next proposition examines the complementing case of disruptive arms denial where the value of delay has important implications. For ease of notation, we denote $\rho = p(1-\delta)$.

Lemma: In the case of disruptive arms denial, the expected value of *delay* equals ρV.

Proposition 2: For *disruptive* arms denial (i.e., $\delta V > C_{AR}$), if the expected value of delay is higher than the cost of denial (i.e., $\rho V > C_D$), then

a) Denial occurs if $V(1-\rho) > C_A + pC_{AR}$, in which case *A* invests in recovering and reconstituting.

b) *A* refrains from acquisition if $V(1-\rho) < C_A + pC_{AR}$

Otherwise, if $\rho V < C_D$, *A* acquires the new capability uninterrupted.

When conditions 2a are met, a *denial cycle* emerges. In this case, *A* chooses to acquire the new capability, which *D* then tries to deny. A successful denial event would be then followed by *A's* attempt to recover and obtain the new capability at a later point in time. A denial cycle occurs when the *expected value of delay* – $p(1-\delta)V$ – is not high enough to deter *A* from acquiring the new capability, but is still high enough to warrant denial by *D*. As explained in the setup of the model, in this context 'buying time' could be highly beneficial for *D*, up to the point that it would engage in denial operations recognizing that these operations would most likely not prevent the acquisition.

Interestingly, according to Proposition 2b, disruptive arms denial may also lead to a *restraint* strategy. In this case, if an acquisition effort is already underway (and its costs are sunk), *A* would choose to attempt to recover from denial. However, when facing the initial acquisition question, the prospects of successful denial combined with the overall costs of acquisition (including recovery) make acquisition unattractive. As in proposition 1b, denial has a strategic effect: *D* needs only pose an implicit credible threat of denial to enjoy denial's benefits. An opposite strategic effect happens when $\rho V < C_D$. Although at face value it is cost-effective for *D* to attempt denial, the high likelihood of successful recovery renders denial a futile act.

Figure 2 depicts the equilibrium strategy-pairs as a function of *V* and *p*, for a given set of parameter values[7]. Notice that when the value of delay is high, there is a wide range of acquisition values and denial probabilities for which the equilibrium strategies entail the exercise of denial. Obtaining the strategic effect of *restraint* requires a high probability of denial success.

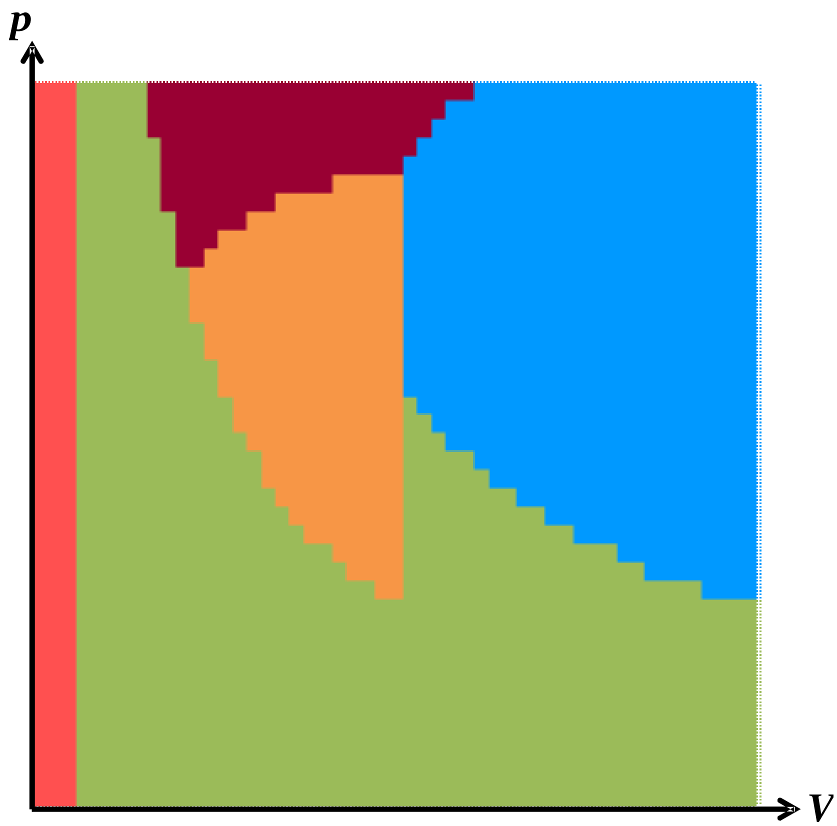

Figure 2: Equilibrium Strategy-pairs as a Function of System Value (V) and Probability of Successful Denial (*p*), other parameter values are fixed as: C_A=0.05, C_D=0.15, C_{AR}=0.25, δ=0.5

Figure 2 is a static representation of optimal strategies for specific parameter values. In reality, however, parameter values are dynamic and may change over time; either because of an exogenous change or as a result of one of the actors' attempt to change the game to its benefit. Propositions 1 and 2 suggest

[7] Values were chosen such that all strategy-pairs are exhibited. We discuss the effect of changes in parameter values in the following proposition.

that actors have four “strategic levers”[8] at their disposal to alter the resulting equilibrium strategies: the cost of denial (C_D), the probability of successful denial (p), the cost of recovery (C_{AR}), the value of delay (δ). The following proposition provides key comparative statics to better understand how changes in parameters affect the actors' equilibrium strategies.

Proposition 3: Comparative Statics

a) For a given V, if A is indifferent between refraining from acquisition and any other strategy, a change in at least one of the following parameters makes *restraint* the optimal strategy: decrease in C_D, increase in p, increase in C_{AR}, and decrease in δ.
b) For a given V, if D is indifferent between allowing uninterrupted acquisition and any other strategy, a change in at least one of the following parameters makes the former the optimal strategy: increase in C_D, decrease in p, decrease in C_{AR}, and increase in δ.

Proposition 3 underlines how actors can take advantage of the “strategic levers” to modify the game in advance and obtain their preferred outcome: *restraint* for *D*, and *uninterrupted acquisition* for *A*. For example, if *D* succeeds in decreasing the cost of denial or increasing its probability of success, and this change then becomes common knowledge, it may suffice to result in *A* refraining from acquisition altogether. This result has important policy implication. Specifically, the result suggests that an early investment in denial capabilities, for example, may deter *A* from trying to acquire a new capability, in which case denial would not be employed. We further discuss these strategic levers and their policy implications below.

[8] We use the term “strategic levers” (as opposed to, say, “tactical” ones) to emphasize that their effect comes from *a priori* choices and investments taken by the actors for the purpose of affecting the other side’s strategic decisions.

5. Discussion

Propositions 1, 2 and 3 identified four equilibrium strategy-pairs - *Attempt*, *Denial Cycle*, *Restraint* and *Uninterrupted acquisition*, and four strategic levers – cost of denial, cost of recovery, probability of denial success, and a delay discount. Below we first present real world examples to demonstrate each equilibrium strategy and strategic lever. We then discuss implications for defense policy, arms races and regional stability.

Equilibrium Strategies

Attempt—Under Attempt, the acquiring actor perceives the probability of successful preventive denial to be relatively low and thus attempts acquiring the desired capability. The perception of this probability to be low could result, for example, from the acquiring actor's effort to keep aspects of its acquisition effort secret (for example, by hiding key facilities, setting up shell companies, etc.). If the denying actor overcomes these difficulties and successfully denies the acquisition, the acquiring actor discontinues the acquisition effort as recovery is costly and bears the risk of a follow-up denial action.

A case in point is Syria's nuclear program. According to Follath and Stark (2009), in the early 2000s Syria contracted North-Korea to *covertly* build a nuclear reactor capable of producing weapons grade Plutonium (based on the latter's indigenous reactor in Pyongyang). Both Syria and North-Korea must have assessed that an *overt* effort to build such a reactor would not only be met with intense international pressure, but would likely lead to a military strike if the effort persisted. Israel's attack on the Iraqi Osiraq reactor in 1981 and the US invasion of Iraq in 2003 were clear precedents, and the US gave North-Korea clear warnings in that regard (Sanger and Cooper, 2006). Facing a highly credible threat of preventive denial, they refrained from a declared project to construct a nuclear reactor. Furthermore, an alternative approach of constructing a highly-shielded and dispersed nuclear enrichment program was not chosen, perhaps because it was too costly, not crossing the prerequisite cost-effectiveness threshold ($V>C_A$).

In contrast, Syria's chosen program hinged on the secrecy of the reactor construction—keeping it hidden until the reactor was to become operational, at which point it would have been *fait accompli*. By keeping it highly covert, Syria and North-Korea likely believed that the overall probability of denial (p) was small enough to run the risk of discovery, given the huge expected payoff from a successful nuclear program, which more than offset the associated costs. Indeed, according to the former US vice President, Dick Cheney (2011), the plan was almost successful, and the reactor has been discovered only shortly before it would have become operational. Following discovery, the reactor was destroyed by an air strike, and Syria is believed to have abandoned its nuclear ambitions.

It is worth noting on the role of uncertainty in this case: while covert programs have been used to justify the use of asymmetric information in other models (e.g., Debs and Monteiro, 2014), the key question pertaining to our analysis is not the extent to which the denying actors suspect the existence of such a program, but rather Syria's *a priori* assessment of the risk of denial, or specifically, the chances that its covert program would be discovered. This uncertainty is shared by both actors, and thus the use of asymmetric information is not warranted for the analysis.

Denial cycle – The *denial cycle* strategy describes the case where the acquiring actor attempts acquisition and the denying actor attempts *disruptive* denial recognizing that even if successful, the former would attempt recovery. This strategy is optimal if the *value of delay* is high enough to justify the costs of denial, or if recovery may not succeed. Thus in the case of disruptive arms denial, it is the value of delay, as opposed to the certainty of prevention that makes denial optimal despite the prospect of recovery. The acquiring actor, in turn, foresees the future delay, yet finds the lofty value from acquisition to be high enough to compensate for the expected future costs of recovery.

Denial cycle is best exemplified by the interactions over Iran's nuclear program. Over the years, numerous attempts to sabotage the program have been reported. Notable examples include the Stuxnet computer virus, which was designed to disable the Iranian enrichment plants, the modifications of dual-use equipment – e.g., power suppliers, vacuum pumps, pressure gauges—to inflict damage to centrifuges, and the assassination of several Iranian nuclear scientists (Sanger, 2012). Our model explains these events as aimed at delaying the Iranian program, rather than preventing it. According to Sanger (2014), this was indeed the intent of "Olympic Games", the alleged US-Israeli covert program against Iran's nuclear program: "What he [Obama] liked about the program [Olympic Games] was that it was covert and that, if successful, it could help buy time to force the Iranians into negotiations". The cyber-attacks left open the question of a military strike against Iran's nuclear program, which we discuss further below.

Restraint—potentially the most interesting equilibrium strategy, *restraint* defines the case where the denying actor's credible threat of denial deters the acquiring actor from trying to acquire the new capability. This strategy is chosen when denial is cost-effective and likely to succeed, while recovery is very costly and has a low probability of success. The rationale for restraint is somewhat different for preventive and disruptive arms denial.

The more straightforward case is that of preventive arms denial, when recovery is not cost-effective for the acquiring actor. In this case, the prospect of denial renders acquisition unattractive. It is difficult to find direct historical evidence for a *restraint* strategy, as one can never know whether a certain player had planned acquisition but chose to dispose of the plan. It is worthwhile to consider a potential externality of the Israeli strike on the Iraqi Osiraq reactor: the strike itself signaled Israel's neighboring countries Israel's relative value and costs of denial in the case of nuclear programs. If any countries in the region contemplated developing a nuclear program, the attack on Osiraq should have played a role in their cost-effectiveness considerations, and potentially contributed to the decision to refrain from such a development. In order to address this risk, the two countries that have developed a nuclear program (Iran and Syria) had chosen a significantly different strategy than Iraq. Specifically, Iran made a huge upfront investment to prevent a single strike from disabling its nuclear program, while as discussed earlier Syria has chosen a highly covert path.

The intuition behind *restraint* under *disruptive* arms denial is more subtle. By definition, the case of disruptive arms denial refers to the situation where *ex-post* recovery is optimal. Consequently, *ex-ante*, the acquiring actor must take into account the overall costs of acquisition *and* recovery. If the overall costs are higher than the expected benefits, *restraint* is the *ex-ante* optimal policy. This presents an interesting policy trade-off for the denying actor: while on one hand keeping denial capabilities secret maintains a tactical surprise and thus increases the probability of successful denial (from an operational standpoint), on the other hand it diminishes the strategic effect of denial—i.e., restraint and thus full prevention. For example, the bug in the code that caused Stuxnet to spread widely and lead to its exposure might have had a strategic effect on Iran and other countries, one that is beyond the additional tactical damage it could have inflicted had it not been exposed (Langner, 2013).

Uninterrupted Acquisition--finally, when denial is not likely to succeed or when recovery is expected and the value of delay is small, the denying actor does not attempt denial and its adversary *acquires* *the new capability uninterrupted.*[9] Going back to Iran's nuclear program example, this is the essence of the much-discussed debate on a military strike against Iran's nuclear facilities: What are the chances that the strike will indeed create significant damage (p)? How costly would be the ensuing Iranian response (C_D)? How likely is Iran to try and recover its program following such a strike (C_{AR})? While this discussion is beyond the scope of this research, our model provides a useful prism for analysis.

Strategic Levers

As in all fields of strategy and warfare, the participating actors strive to strategically change the parameters of the game to their benefit. A denying (acquiring) actor would aim at forcing the acquiring (denying) actors to refrain from acquisition (denial) instead of being caught in a costly denial cycle. What are the strategic levers at their disposal? The comparative statics results (Proposition 3) provide guidance for this question.

Cost of denial (C_D) & the probability of denial success (p): An acquiring actor would aim at *increasing* the cost of denial and decreasing the probability of successful denial. This can be done, for example, by dispersing facilities geographically or by using physical fortifications, which increase the cost of a kinetic attack. The acquiring actor may also offer civilian-use justifications for military programs in order to increase the political and diplomatic costs of denial. Iran, for example, has employed such measures in its nuclear program. Alternatively, the acquiring actor could find a "denial immune" patron for the supply of arms – an increase in arms sales by China, for example, may signal such a strategy.

[9] Recall that the value of denial is assumed to be higher than its costs. When this condition does not hold, uninterrupted acquisition is trivially the optimal policy. Indeed, this seems to be a common case.

In contrast, a *denying* actor would try to *decrease* the costs of denial. This can be done, for example, by embarking on a research and development effort aimed specifically at denial capabilities, or by establishing dedicated sub-organizations that would create economies of specialization in denial. Furthermore, the tendency of arms denial to be non-attributable could be interpreted as decreasing the cost of denial and increasing the probability of its success, as it allows the denying actor to evade the diplomatic costs associated with unilateral denial attempts and may keep the element of surprise in future denial attempts.

Cost of recovery (C_{AR}): An acquiring (denying) actor would aim to decrease (increase) the cost of recovery. From the acquiring actor's side, investment in backup options could signal the denying actor that following denial, the acquiring actor can recover relatively quickly and with relatively low costs. Alternatively, investing in technical self-reliance allows it to be less dependent on external help, and thus signals a better capability to recover.

From the denying actor's side, demonstrating the capability to use multiple denial methods (so recovery would be prolonged) would lead the acquiring actor to expect higher recovery costs, as would the use of obfuscated denial effects. For example, according to Langner (2013), Stuxnet was designed to cause the operators to believe they have reliability issues rather than understanding that they are under attack. This, in turn, translated to a lengthy investigation and higher recovery costs.

Erosion of value over time (δ): As discussed earlier, the value of delay stems from the length of delay, the probability that exogenous factors will affect the status quo, and potentially the decreasing in the operational value of the new capability over time. Consequently, the higher the value of delay, the more likely is denial. An acquiring actor, for example, could try to convey its full commitment to the acquisition of the new capability, regardless of future political changes, thus mitigating the importance of potential external events as a component in the value of delay. For example, Iran often emphasizes the broad popular support for its nuclear program, suggesting that even a regime change would not change its course.

From the perspective of the denying actor, an emphasis on the development of defensive systems significantly decreases the value to the acquiring actor of the acquired capability. In tandem, denial efforts and defensive systems may serve as a powerful deterrent to the acquisition of a new capability.

The framework of strategic levers allows for the interpretation of the behavior of acquiring and denying actors through the lens of our model. More importantly, it offers a tool to analyze and predict possible future trends in this field. We now turn to discuss the implications of these trends on international security.

Implications for international security

As arms denial becomes an inherent part of international conflicts, the overall effect of this interaction raises new questions. In particular, how does the co-existence of military build-up and open conflict (that is short of war) affect arms races and the overall regional stability?

Arms races describe the interaction of actors who engage in military capability buildup to better prepare for future conflicts and to deter their opponent from waging war upon them. From an arms race perspective, arms denial *slows down* the overall pace of capability acquisition on both sides: The acquiring actor may refrain from the acquisition of certain capabilities (because of the threat of denial), increase the investment per acquired capability (to employ the strategic levers discussed above or to recover from denial) and suffer disruptive arms denial attacks. The denying actor, on the other hand, has to invest resources in the development of denial capabilities and carry out denial operations; slowing down its own capability buildup.

In a sense, arms denial upends the arms race paradigm: actors employ aggressive methods (be it diplomatic, clandestine, or military) in order to disrupt the other side's buildup process. This, in turn, creates a new *arms-denial* race in which actors compete for their capability to deny and to evade being denied.

This tendency toward more frequent use of force in peacetime to prevent capability acquisition raises the question of regional stability, as small skirmishes could potentially escalate into full-fledged armed conflicts. While a formal treatment of this topic is left for future research, a few preliminary thoughts are possible. Seemingly, there are restraining forces influencing both actors in an arms denial. For the acquiring actor, a strong retaliation following an event of denial might lead to war; jeopardizing the entire acquisition effort. For the denying actor, had a full preventive war been optimal, it would have chosen this path in the first place. Thus, by the logic of revealed preferences, the choice of arms denial signals that the denying actor is better off keeping the conflict contained. These shared interests could provide another explanation to the frequent use of non-attributable denial methods: by refraining from assuming responsibility, the denying actor reduces the acquiring actor's reputational costs for not retaliating, thus allowing both sides to keep the status quo within the boundaries of arms denial cycle: acquisition, denial, and recovery attempts. We therefore expect arms denial to not increase the probability of wars, but rather increase the frequency of violent incidents. This leaves open the question of the effect of this increased level of hostility on the prospects of two such actors to engage in diplomatic efforts to solve the underlying conflict.

6. Conclusions

As countries aim to prevent their adversaries from acquiring new military capabilities, arms denial emerges as a central and oft-used strategy. The unilateral and limited nature of arms denial turns it into a potentially attractive alternative, or complement, to bilateral diplomacy and preventive wars. Despite the dozens of arms denial events reported in the last decade alone, there has been a gap in the scholarly literature on this topic. Our paper aims to fill this gap.

The paper presents a conceptual framework for the analysis of arms denial and its strategic aspects. As arms denial is no longer a rare, or surprising element of counter-proliferation, both the denying and the acquiring actors are expected to account for it in their strategic choices. We show that this could lead to several notable and counter-intuitive equilibrium behaviors. In particular, the strategic effect of denial and recovery may lead an acquiring actor to refrain from a cost-effective acquisition, because of the fear of denial. Alternatively, the prospects of successful recovery may grant the acquiring actor the possibility to acquire the capability uninterrupted. The prospects of recovery, however, do not always prevent denial. Specifically, if the value from "buying time" is high, denial is optimal even if recovery is expected. In addition, we show that if denial failure is likely, investing in new capabilities despite a risk of denial could be optimal. Finally, we find that there are strategic investments that both sides could undertake to modify the decision of the other side to their advantage.

The contribution of our framework and results to the scholarly literature is threefold: First, we address through a unifying lens a broad class of diplomatic, clandestine and military activities, which have so far been mostly discussed separately. Second, the resulting equilibrium strategies and strategic levers provide a coherent rationalist explanation to many occurrences of arms denial events, such as the case of the Syrian reactor *attempt* strategy or the *denial cycle* evident in the case of the Iranian nuclear program. Last, the simplicity of the model and the richness of its results yield predictions that lend themselves to empirical investigation in the field of arms denial.

From a policy perspective, the results of the model have implications for both denying and acquiring actors. Given that countries might find themselves on both sides of arms denial interactions in different cases, both perspectives are of importance. For a (potential) acquiring actor, arms denial should become an integral part of the weapon acquisition calculus, as part of the decision to acquire. The future risk of denial needs to be accounted for, as does the strategically managed use of the levers mentioned above. For a denying actor, the key dilemma emanating from the paper is that of the strategic use of arms denial, which benefits from an explicit strategy and a visible effort to increase arms denial capabilities, versus the more tactical considerations that support secrecy and surprise. The right balance needs to be found, if an actor wishes to benefit from the value of arms denial as a tool to deter the acquisition of new capabilities.

Our paper can serve as a foundation for future research in several directions. While we support our theoretical findings with numerous real-life examples, there is much room for deeper historical analyses of past cases to explore the details of the strategic arms denial interaction. In particular, the strategic choice of *restraint* provides a challenging hypothesis to further explore in empirical research. In addition, as our research views arms denial as a whole, a next step would be to analyze the various methods of arms denial, and better understand the reasons for the choice of one method over the other along multiple dimensions. More importantly, one could analyze the “portfolio management” of an arms denial campaign that uses more than one method. Finally, as mentioned at the outset of the paper, arms denial is only one of several counter-proliferations strategies. A research of the interplay of diplomacy, arms denial and preventive wars, could lead to a much needed overarching theory of counter-proliferation.

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Appendix

Proposition 1

We solve by backward induction.

Given the assumption that $\delta V < C_{AR}$, in stage 3, *A* would not choose to recover from a successful denial. In stage 2, it is therefore optimal for *D* to deny the acquired capability from *A* if the expected value of denial is higher than the alternative of uninterrupted acquisition, namely:

$$p(-C_D) + (1-p)(-V - C_D) > -V$$

Rearranging yields: $pV > C_D$, which holds given the proposition's assumption.

It remains to find the conditions under which, in stage 1, *A* would choose to acquire (attempt strategy) or refrain from it (restraint strategy).It is optimal for *A* to attempt acquisition if:

$$p(-C_A) + (1-p)(V - C_A) > 0$$

Rearranging yields the following condition (Proposition 1a): $(1-p)V > C_T$. If this inequality does not hold, it is optimal for *A* to refrain from acquisition, and Proposition 1b holds.

If : $pV < C_D$, *D* would not deny, and as $V > C_A$, it is optimal for *A* to acquire. **Q.E.D.**

Lemma 2

In stage 3, given the assumption that $\delta V > C_{AR}$, *A* would try to recover following a successful denial.

Going back to stage 2, the expected value of denial for *D* then equals:

$$p(-\delta V - C_D) + (1-p)(-V - C_D)$$

Denial is optimal if its expected value is higher than the alternative, which is –*V*. That yields the condition for denial: $p(1-\delta)V > C_D$.

Proposition 2

In stage 1, *A* chooses to acquire if:

$$p(\delta V - C_A - C_{AR}) + (1-p)(V - C_A) > 0$$

Rearranging yields the condition of Proposition 2a: $p(1-\delta)\mathrm{V} > C_A + pC_{AR}$

If this equality does not hold, *A* then refrains from acquisition—as in the second part of the proposition.. Under the assumption that $p(1-\delta)V < C_D$, D does not deny, and it is optimal for *A* to acquire.

Q.E.D.

Proposition 3a

For restraint to be the equilibrium strategy for *A*, either the conditions in Proposition 1b or in Proposition 2b have to hold in strict inequality If *A* is assumed to be indifferent between restraint and any another strategy, then at least one of these conditions has an equality. We continue by analyzing the various possible cases. For each case, we find the parameter value change required to turn restraint to be the strictly preferred equilibrium strategy:

1. $\delta V < C_{AR}$, $pV = C_D$, $(1-p)V \leq C_A$

    a. If p increases (that is, $p' = p + \varepsilon$; $\varepsilon > 0$) then $p'V > C_D$, $(1-p')V < C_A$, obtaining the required condition in Proposition 1b.

b. If C_D decreases (that is, $C_D' = C_D - \varepsilon$; $\varepsilon > 0$) then $pV > C_D'$. Proposition 1b then holds; unless $(1-p)V = C_A$ (in which case an increase in p is also required).

2. $\delta V < C_{AR}$, $\geq C_D$, $(1-p)V = C_A$

a. An increase in p (that is, $p' = p + \varepsilon$; $\varepsilon > 0$) yields $p'V > C_D$, $(1-p')V < C_A$, and Proposition 1b holds.

3. $\delta V \leq C_{AR}$, $p(1-\delta)V = C_D$, $V(1\text{-}p(1-\delta)) \leq C_A + pC_{AR}$

a. An increase in p (that is, $p' = p + \varepsilon$; $\varepsilon > 0$) yields $p'(1-\delta)V > C_D$, $V(1\text{-}p'(1-\delta)) < C_A + pC_{AR}$, and Proposition 2b holds (unless $\delta V = C_{AR}$).

b. A decrease in C_D (that is, $C_D' = C_D - \varepsilon$; $\varepsilon > 0$) yields $p(1-\delta)V > C_D'$. Proposition 2b then holds unless $V(1\text{-}p(1-\delta)) = C_A + pC_{AR}$ (in which case other changes are also required).

c. A decrease in δ (that is, $\delta' = \delta - \varepsilon$; $\varepsilon > 0$) would lead to the desired result (similar to case 3a).

4. $\delta V \leq C_{AR}$, $\rho V \geq C_D$, $V(1\text{-}\rho) = C_A + pC_{AR}$

a. An increase in p (that is, $p' = p + \varepsilon$; $\varepsilon > 0$) yields $p'(1-\delta)V > C_D$, $V(1\text{-}p'(1-\delta)) < C_A + p'C_{AR}$; and Proposition 2b holds.

b. An increase in C_{AR} (that is, $C_{AR}' = C_{AR} - \varepsilon$; $\varepsilon > 0$) yields $V(1\text{-}p(1-\delta)) < C_A + pC_{AR}'$. Proposition 2b holds unless $p(1-\delta)V = C_D$ (in which case other changes are also required).

c. A decrease in δ (that is, $\delta' = \delta - \varepsilon$; $\varepsilon > 0$) leads to the conditions required for Proposition 2b to hold (similar to case 4a).

Q.E.D.