Minimal Nuclear Deterrence

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This article develops a rational theory of *minimal* nuclear deterrence: What is the minimal amount of weapons needed to maintain a stable balance of power? By searching for the requirements of minimal nuclear deterrence, we hope to gain a better understanding of how to proceed with arms reduction without compromising the value of deterrence.

In thinking about the nuclear arms race, the terminology can be counterproductive. Calling it a race suggests winners and losers. But unlike a footrace, an arms race can end with the outcome being left unresolved. How far must the race be run before both parties agree to a perpetual draw? The purpose of this article is to develop a rational theory of *minimal* nuclear deterrence: What is the minimal amount of weapons needed to maintain a stable balance of power? By searching for the requirements of minimal nuclear deterrence, we hope to better understand the possibilities for arms reduction, how far we can go without compromising the value of deterrence.

> The most important task at this stage is to define the bottom line of nuclear deterrence, to come to an alliance agreement on what the minimum is, rather than to leave the definition to an uncontrollable process in which the internal politics of alliance members interact with Soviet initiatives.
>
> Karl Kaiser (1987), commenting
> on the U.S.-Soviet INF negotiations

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At the 1988 levels of weaponry, neither the U.S. nor the USSR has a serious fear of a premeditated attack. With 12,000 warheads, we have mutual deterrence, but it is not minimal. Were both superpowers to disarm down to zero nuclear weapons, we would move to an opposite extreme: Nuclear weapons become minimal but nuclear deterrence is lost.[1]

Without nuclear arsenals, the presence of mutual distrust would lead to concern over a hidden nuclear rearmament (and a preemptive rearmament to prevent the surprise). The ease of attaining a dominant position results in a breakdown of deterrence. Somewhere between 0 and 12,000 is a dividing region. Minimal nuclear deterrence describes the limit on disarmament. If we can demonstrate that this limit is in the distance, it may be easier to head in that direction.

Section 1 presents the motivation for minimal nuclear deterrence. Section 2 describes the formal model. It is a development and mathematical formalization of Schelling's (1960) essay "Surprise Attack: A Study in Mutual Distrust." The equilibrium is illustrated through an example in Section 3 with extensions provided in Section 4. Conclusions and policy implications are offered in Section 5.

HOW MUCH IS ENOUGH?

In an adversarial relationship, there are many reasons to fear an attack. A country that fears it is in imminent danger of being attacked might prefer to preempt. A country that perceives it has a dominant position may then feel forced to attack in order to prevent being preempted. Whenever both sides foresee a change in their power relationship there is a mutual fear of preemption. An attack may be the outcome of this destabilizing spiral of expectations. The solution is to eliminate the fear: Both countries must be confident that the other has nothing to gain from an attack. Deterrence involves preventing a premeditated attack as well as preventing a preemptive attack.

In discussing a premeditated attack, we want to include the possibility that the attack capability is used as a threat. Deterrence fails when one side has a credible attack capability, an *ability* to attack without fear of

1. In this article, we are ignoring the interesting and important issues associated with conventional war and deterrence.

reprisal. In this event, a country can either use its weapons directly or use them as a threat in order to force a rival to be docile (see McGuire, 1965). We will focus on the requirements for an attack capability. When this capability is denied, then the threat is not credible, and an attack is not rational. The goal of deterrence, therefore, is to deny an attack capability, however it may be used.

It might appear that we are leaving out discussion of a preemptive strike as a type of attack. But once we eliminate the possibility of a rational attack, we simultaneously solve the problem of preventing a preemptive strike. A preemptive strike is chosen only as a second-best alternative. If we eliminate the fear of a premeditated attack (or credible threat capability) there is nothing needed to preempt.

The possibility of a breakdown in mutual deterrence can arise through two channels: quantity and quality. An arms buildup can be done in secret, leading to a surprise in the quantity of weapons. A country attempting to achieve a dominant position may try to take advantage of the difficulty in achieving perfect monitoring to build up its weapons supply secretly before initiating a conflict. Alternatively, a technological advance may lead to a discontinuous increase in the quality of weapons. This qualitative surprise could provide the advantage needed to attain a credible attack capability.

At present, advances in quality are the much more relevant issue. Certainly, neither of these possibilities is considered very likely. But a scientific advance that led to a functioning "Star Wars" defense would be a technological surprise that changes the balance of power. Again, it is important to emphasize that we are seeking the requirements for *minimal* nuclear deterrence. If there are deep cuts in the number of nuclear weapons, then the possibility of achieving a dominant position through a hidden rearmament rearises as a much more serious concern. Furthermore, surprises need not be all or nothing. We can discover that the Soviets have a head start and worry that we may not be able to catch up in time.

A DYNAMIC MODEL OF DETERRENCE

Mutual deterrence is based on symmetry; both sides are strong enough to prevent an attack. The attack (or threat) they seek to prevent does not necessarily arise from this position of equality. To consider a rational attack capability, one side must be so far ahead of the other that it may credibly threaten to attack without fear of mutual destruction.[2]

Nuclear deterrence must wear two hats. The traditional view is that attacks must be prevented from the current level of weaponry. In particular this includes preventing preemptive strikes. The other role of deterrence is to ensure that neither side has any incentive to attempt a move away from the status quo. This second condition is the central point of this article. If you can deny an opponent an incentive to launch its optimal attack (and you yourself are equally denied) then neither side need fear the suboptimal attack from a preemptive strike. Schelling's mutual fear of surprise attack is eliminated by stopping the expectations spiral at the first step. When a credible attack capability seems impossible, there is nothing to preempt and the initial fear need not arise.

To see how to preserve the status quo, we consider how it might be disrupted. Here, we need to model the dynamic interaction of an arms race. Unfortunately, this is a difficult task. There is no simple way to integrate dynamic interactions with the discrete choice of regimes, to maintain the status quo or to attempt dominance.

In a Nash equilibrium, for example, countries may consider the discrete change in strategy inherent in a move to an attack capability.[3] But Nash equilibrium is a fundamentally static interaction. By leaving out dynamics, it rules out the possibility of collusion that can make both countries better off. Even rival countries have an incentive to reach arms control agreements. Agreements can be made provided it is in the self-interest of both parties to maintain them. To see what types of agreements are feasible, we need to model how countries will respond to a reduction in arms.

The continuous adjustment models (see Richardson, 1960) capture interactive responses but have other problems. The essence of a change in strategy, from maintaining deterrence to attempting dominance, is that it involves a discontinuous change in behavior. The differential equation adjustment models focus on local changes in behavior and

2. The world is more complicated than this simple intuition. The technology of MIRVed missiles suggests the possibility of attacking from behind. To the extent this is possible, it destroys the possibility for any type of nuclear deterrence, minimal or otherwise. This issue is discussed in Section 4.

3. See, for example, McGuire (1965), Brown (1971), Intriligator and Brito (1975), and Brito and Intriligator (1982).

thereby miss the incentive to jump toward an attack capability.

The Stackelberg equilibrium is a step in both directions. One country is specified as a leader and the other as a follower. The leader chooses weapons first, anticipating the follower's response. The leader will want to have a sufficiently large arsenal that the follower prefers to engage in mutual deterrence rather than attempt to surprise with an attack capability. This approach has been successfully followed by Brito (1972). He shows that if either one or both countries behave as a Stackelberg leader then there will be a stable outcome to the arms race.

While this is an important advance, it goes only halfway. In Stackelberg competition only the follower is responding to the leader. In an arms race, both sides are responding to each other: There is no natural leader, nor follower. Our goal is to employ a model of equilibrium that captures the simultaneous adjustment responses implicit in the Richardson differential equation model and yet maintains the possibility of discontinuous responses implicit in Nash and Stackelberg.

Our approach is to allow the two sides to take turns between leading and following (Cyert and DeGroot, 1970). In period 1, one side moves and its action is then fixed until its next turn in period 3. In period 2, the other side responds to the first move in period 1, anticipating that its course will be fixed until it moves again in period 4. In this setting, the strategic player is looking both backward and forward with each move, responding to the other's previous action while setting a precedent for the rival's next move.[4]

To translate the Cyert and DeGroot model to capture competition in the arms race requires some important changes. As in their model, each period the country responds to its adversary's last period move and then chooses a new level of arms anticipating its adversary's next move. But while the two countries are alternating moves, neither side is guaranteed another turn. *If either side achieves a credible attack capability, the game is over.* The game is over because deterrence has broken down. If one side ever achieves a dominant position, it has the power to change the rules.

4. Maskin and Tirole (1988) develop the Cyert and DeGroot model to examine a different type of deterrence: entry deterrence. A firm builds sufficient capacity in one period that when it is the other's turn to move, it faces an initial loss during the first period of entry that is more than enough to offset any subsequent gains from capturing the market.

While deterrence is maintained, the game continues. When it is a country's turn to respond to its rival's move, it faces a dichotomous choice. It can preserve or disrupt status quo. If it chooses to reach an attack capability, the game is over: The other country does not get another chance to respond. If it chooses to maintain the status quo, it can predict that the game will continue. The objective then becomes to deter the other side from attaining an attack capability in the next period. If one side chooses not to end the game, it wants to ensure that its rival is also induced to continue playing.

The decision making can be thought of in two stages: Do I want to have an attack capability? If not, what must I do in order to deter? In choosing whether or not to seek an attack capability, I act as a follower, responding to the other's move. Then, if I allow the game to continue, I act as a leader, anticipating the other side's response.

Even here, the alternating moves model suggests a certain artificiality that somehow the decision intervals are discrete. This too we want to avoid. To approximate the simultaneous adjustment process, consider the equilibrium of the alternating moves game in the limit as the time period between moves goes to zero. As the time periods become shorter, we can approach a model with continuous decision making. The rapid alternation is meant to blur into simultaneous moves. There is neither a leader nor a follower. Both countries are on equal footing.

Mutual nuclear deterrence is achieved when both sides build a sufficient number of arms so as to motivate the other to respond by deterring rather than moving to an attack capability. Minimal nuclear deterrence is the smallest number of weapons that leads to mutual nuclear deterrence. To be more formal, minimal nuclear deterrence holds when

(1) given country II's defense and country I's current weapon supply, the expected gain to country I from pursuing an attack capability is not justified by the expected cost
(2) given country I's defense and country II's current weapon supply, the expected gain to country II from pursuing an attack capability is not justified by the expected cost
(3) if either country I or country II were to have fewer weapons, then one side (or both) would find it worthwhile to pursue an attack capability[5]

5. It is not obvious that such a minimum level will always be well defined. In the analysis that follows, the requirements for deterrence are monotonically increasing in the level of the other side's weapon supply. This monotonicity guarantees that there will be no ambiguity in characterizing the minimum.

Given current arms levels, neither side should be prepared to attack the other. Equally important, both sides must be deterred from seeking a surprise buildup that could lead to an attack capability.

AN EXAMPLE

A stylized example can provide concrete insight into the workings of minimal nuclear deterrence. For purposes of illustration, the arms race between the U.S. and the USSR is grossly simplified to three features below.

(1) The stock of weapons consists only of land-based nuclear missiles. Each costs $1 to produce. The quality of these weapons is fixed.
(2) An attack capability is achieved when one side has three times as many missiles as the other. The value of this threat is $100. The loss of being threatened is –$1,000.
(3) Missiles last only two periods. Each country looks forward only two periods into the future when calculating its optimal strategy.

These gross simplifications leave out many essential elements of the arms race. Since the quality of missiles is fixed, surprises arise only through changes in quantity, not quality. The two-period time horizon is a simple substitute for time discounting. We present this stylized model to focus attention on the decision-making process that leads to equilibrium. After the solution is illustrated, we will return to present a more critical view of these abstractions and to develop the example into a more realistic portrait of the arms race.

Minimal nuclear deterrence arises at (50, 50). Both the U.S. and the USSR are secure against buildups to an attack capability when they each maintain a supply of at least 50 missiles. For the USSR to achieve an attack capability over the U.S., it would need a total of 150 missiles. To attain 150 missiles requires a 100-missile expansion over the stock needed for deterrence. The cost of this expansion is $100, just enough to offset the $100 gain.

If both countries have more than 50, then there is mutual deterrence, but it is not minimal. For example, at (60, 60) the U.S. needs a total of 180 to achieve dominance over the USSR. The cost of a 120-missile expansion is not worth the expected $100 gain. In fact, each side has a *unilateral* incentive to disarm. A small reduction in missiles will not induce the other side to disrupt the status quo. The U.S. need only build 160/3, or 53 1/3, missiles to deter the USSR. The USSR, responding to a

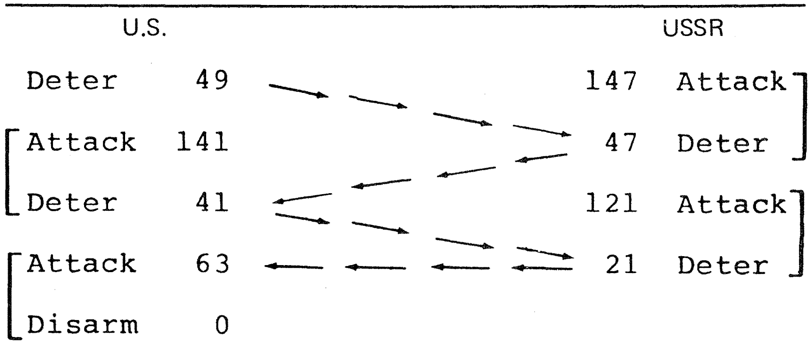

Figure 1: Instability of Disarmament Spiral

U.S. reduction to 53 1/3, recognizes that the U.S. will not want to attempt a buildup if it requires more than 154 missiles. Therefore, the USSR is safe with anything over (153 1/3)/3 or 51 1/9. Extending this series forward, disarmament will continue until (50, 50) is reached, the minimum level needed for mutual nuclear deterrence.

In contrast, if either side goes below 50 it will have gone under the minimum and mutual deterrence breaks down. Starting at (50, 50), imagine what would happen if on the U.S. move it decides to lower its inventory to 49. Next period, the USSR responds. With the U.S. at 49, the Soviets can achieve an attack capability at 147. It compares this with choosing a deterring strategy of building 50. The attack option is now worthwhile: It costs 97 more than deterring but leads to a gain of $100.

Of course, there is another option. The Soviets find it equally profitable to disarm down to 47. This suggests the possibility of a disarmament spiral. Why do we conclude that the Soviets would choose to attain a credible attack capability rather than follow with disarmament?

The problem with a disarmament spiral is that it must eventually stop; at that point the two countries are out of equilibrium. Both sides can look forward and recognize the future instability of the disarmament path. Since neither side is willing to be caught at the end, it follows that both cannot be willing to pursue this path. One side must always prefer to attack now rather than be caught later. To see how deterrence unwinds if either country ever has less than 50 missiles, we follow the dynamic process of alternating moves.

As above, start at (50, 50) and consider a deviation by the U.S. from 50 down to 49. In the next decision interval, the USSR can end the game by building up to an attack capability of 147. The net value of this approach is –$47. In order for another alternative to be as appealing, it must be able to deter the U.S. with a missile supply of less than 47.

The USSR will choose the disarmament route down to 47 only if it believes the U.S. will not see this as an opportunity to reciprocate with an armament up to an attack capability. How will the U.S. respond to 47? It can now achieve an attack capability at 141 missiles. This leads to a payoff of –$41. In order for disarmament to be equally attractive, it must be able to reduce its weapon supply to 41 or less. This it will be willing to do only if it does not run the risk of losing $1,000 by being the recipient of an attack threat in the next period.

The chain continues, with the USSR now faced with the option of achieving an attack capability at 123. For disarmament to be preferred, the Soviets must reduce down to 23. At this point, the disarmament spiral breaks down. The U.S. can achieve an attack capability with only 69 missiles. For disarmament to be equally attractive, it would have to go down to a negative level of arms, –31. This is impossible.

The USSR would realize that it cannot deter the U.S. with 23 or less and so it prefers to make a preemptive move toward an attack capability in the previous round when the U.S. had only 41. Of course, the U.S. can anticipate that the USSR will choose to attempt an attack capability. Hence, it will preempt one step earlier when the USSR has only 47.

Right from the start, the USSR must look forward and reason backward. It can predict that when the U.S. is down to 49 it has just one chance to achieve an attack capability. Dominance is worthwhile since it has a gain of $3 relative to deterring at 50. If it waits and reciprocates, the U.S. will do unto them what the Soviets should have done first.

It is possible to calculate the level of arms needed for minimal nuclear deterrence by working backward using the fiction that there is some final date of competition. Imagine that the U.S. moves last. It will either move to an attack capability or build nothing (because there is no value to missiles after the last period). For the U.S. to be indifferent between these two options requires that the number of missiles needed for an attack capability is 100. Hence, in the previous round, the USSR must have built at least 33 1/3 missiles in order to deter the U.S. For the Soviets to have been willing to allow the game to continue, it must have been preferable to deter with 33 1/3 rather than to achieve an attack capability. To ensure that the Soviets will choose deterrence, the U.S. must have built enough missiles in the previous round so that attacking requires more than 133 1/3 missiles. Hence, in the third to last round, the U.S. must have built (133 1/3)/3 missiles.

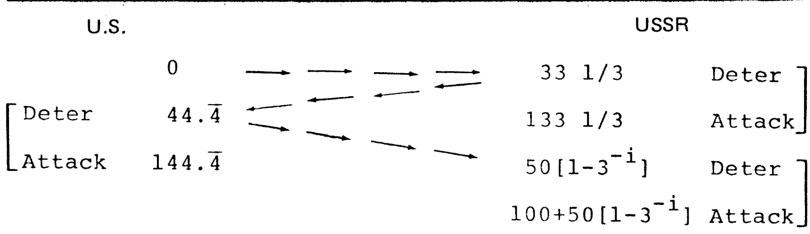

Figure 2: Convergence to Minimal Deterrence

In each period i, the side moving must be indifferent between deterring at some level d_i and attacking at $100 + d_i$. As illustrated in Figure 2, when there are i periods remaining, the minimal level of missiles needed for deterrence is $d_i = 50[1 - 3^{-i}]$. It follows directly that as the number of periods remaining becomes large, the missile supplies wind upward toward their asymptotic limit of 50.

EXTENDING THE MODEL

On its first pass, the model has been based on assumptions that clearly oversimplify the arms race and even miss some of its more important features. Presently, we consider the effect of changes in the cost of arms, valuation of winning, and ratio needed to achieve an attack capability.

Initially, both sides are symmetric, each needing only 50 missiles to deter the other. When there is an imbalance, it is doubly unfair that it is the weaker side that must be the one to maintain the greater weapons stock. The two equations that determine minimal nuclear deterrence are

U.S: [USSR deterrence level × U.S. attack ratio - U.S. deterrence level] × U.S. Cost/Missile = U.S. win value

USSR: [U.S. deterrence level × USSR attack ratio - USSR deterrence level] × USSR Cost/Missile = USSR win value

In this model, weakness can take on any of three meanings. The U.S. can find winning less valuable than the USSR, the U.S. can find missiles more costly to build, or the U.S. can require a larger attack ratio. To take the first example, winning might be worth only \$20 to the U.S. compared to the USSR valuation of \$100. Substituting these values into the equations above, we find that the new minimal deterrence levels are (40, 20) with 40 for the U.S. and 20 for the Soviets.

$$\text{U.S: } [20 \times 3 - 40] \times 1 = 20; \quad \text{USSR: } [40 \times 3 - 20] \times 1 = 100$$

An equivalent weakness would be a production cost of \$5 per missile for the U.S. compared to a \$1 cost for the USSR. Again, minimal deterrence is (40, 20).

$$\text{U.S: } [20 \times 3 - 40] \times 5 - 100; \quad \text{USSR: } [40 \times 3 = 20] \times 1 = 100$$

A third variation that leads to the same outcome is a change in technology that requires the U.S. to have seven times the missile supply of the Soviets, while the Soviets need only a multiple of three in order to achieve a surprise attack capability.

$$\text{U.S: } [20 \times 7 - 40] \times 1 = 100; \quad \text{USSR: } [40 \times 3 - 20] \times 1 = 100$$

In practice, calculating the value of an attack capability is immensely complicated. The value of threatening an attack depends in part on the probability that the threat will have to be carried out. This may involve estimating the perceived value of winning after destroying most of what has been won. But it is not the average citizen's value that counts; it is the value of winning to the politicians and generals who hold the power to make these decisions. Even these decision makers' *actual* calculations are not important. What matters is what the other side believes them to be. As with Romeo and Juliet, misperceptions can turn into realities. Two countries can be in a position of deterring each other even when neither is expansionary; it is sufficient that each has a belief that the other one is.[6]

The ratio needed to make a credible threat depends largely on the expected sequence of counterface and countervalue exchanges should an attack occur (see Intriligator, 1975). There is no doubt that the relative level of arms needed to have a surprise attack capability is more

6. Focusing on rivalry as the cause of armaments leaves aside other important motivations for building arms that arise from political opportunism, employment gains, and technological research. For a discussion of these issues, see Intriligator (1982).

complicated than just a factor of three. It depends on both the size and the composition of military forces.[7]

All else equal, the ratio needed to achieve an attack capability should be a rising function of the number of missiles. Look at this just in expected value terms. If twice as many missiles are launched against twice as many targets, we expect there will be twice as many surviving missiles.[8] When both sides maintain more weapons, going up by the old factor will not be enough to achieve a credible attack capability. Conversely, as weapon stocks are reduced, the margin of deterrence falls at a faster rate.

Although the missiles are constructed instantaneously, this too is an abstraction. The buildup may take place over several periods. A country attempting a secret buildup faces a trade-off between speed, secrecy, and cost. There are also gains from strength other than the ability to make a credible attack threat. Even credibility comes in degrees. The more the power distribution is lopsided, the more credible is the threat. While these features are all essential to model, they do not change any of the basic structure.

So far, the model has focused on achieving an attack capability through a jump in the quantity of weapons. Similar results follow for jumps in quality. There is of course a problem in that one cannot just decide to make a technological breakthrough. The payoffs all have to be translated into expected values. We have to examine the expected probability of success for a technological advance and its expected magnitude. Deterrence requires that the other side does not even attempt these types of technological breakthroughs, since in the long run if there are enough attempts, something will eventually succeed.

One implication of the basic model is that a cause of arms escalation is changes in technology that make attaining an attack capability less costly. In this regard, MIRVed weapons would seem to be a prime suspect. *If the ratio of weapons needed to attack is less than one, then no level of arms can result in mutual deterrence!* This can be seen from the pair of equations determining the minimal deterrence levels. With a

7. Kent (1963) and Brown (1977) persuasively argue that no single indicator is a reliable measure of overall strategic strength. Brown describes the difficulties with eight of the most commonly discussed indicators: (1) the number of launch vehicles, (2) megatonnage, (3) equivalent megatonnage, (4) throw weight, (5) number of warheads, (6) lethality, (7) equivalent weapons, and (8) overall military spending.

8. Doubling the number of missiles also doubles the standard deviation, which again works against the attacker. For more detail on this approach, see McGuire (1965).

ratio less than one, attacking is cheaper than deterring and brings with it the reward of dominance. Since this strategy is better on both counts, there is no incentive to deter. Fortunately, although some type of land-based missiles may have a ratio less than one, in aggregate, when one combines submarine and air-based missiles, the average ratio remains above one.

Research and development can either help or hurt the prospects for deterrence (see Brito and Intriligator, 1981). It helps when we find a change in technology that makes a surprise buildup more difficult to achieve or less effective. This has the effect of raising the cost of achieving any increase in weapons above the deterrence level. Hence mutual deterrence is still possible, even with a reduced weapons supply.[9]

The basic idea is to change the relative costs facing the other side so as to make strictly retaliatory weapons relatively more attractive than arms that can be used primarily for a first-strike capability. This can be thought of as a way of raising the ratio. Clearly, the development of submarines was helpful in this regard.

Minimal nuclear deterrence requires preventing any incentive to reach for an attack capability. Since this capability depends on both the quality and the quantity of weaponry, agreements that make jumps in either dimension more difficult can lower the supply of weapons needed to maintain deterrence. Agreements to improve monitoring (e.g., tolerating spies, satellite technology, and on-site inspections) increase the difficulty of achieving a quantitative jump. Restrictions on testing handicap research and development efforts and thus make it more difficult to achieve a qualitative jump in weapons. Still, there are limits on what agreements can accomplish. If the testing agreement is violated by a successful test that demonstrates a qualitative jump toward a threat capability, it may be too late to punish the violator.

CONCLUSIONS

The theory of minimal nuclear deterrence highlights the degree of cooperation that two mutually suspicious countries can achieve. If

9. Schelling (1967) observed that one might even want to give away technological information that could minimize false alarms or reduce fallout. More recently, President Reagan has made similar remarks regarding sharing the results from the Strategic Defense Initiative.

perfect *monitoring* and *enforcement* of agreements were somehow available, then both sides would have great incentives to reduce their weapon supplies. But there is no supreme enforcer. Maintaining the agreement must be in both sides' self-interest; the expected cost of breaking the agreement must outweigh the expected benefit.

Without monitoring and enforcement, the noncooperative solution becomes unstable at low levels of arms. It is the expectation that agreements will be broken that blocks the disarming chain from dominoing down to zero. At low enough levels, at least one side will have an incentive to break any agreement and attempt to achieve a dominant position. The rational fear of a violation puts a limit on how far one can trust an opponent to disarm rather than attack.

Behind this conclusion is the premise that the less you have, the easier it is to be dominated. It is much harder to develop an effective jump on someone with 12,000 missiles than someone with none.

This theory implies that once countries have reached a minimal nuclear deterrence level of arms, further arms negotiations cannot work by themselves. Both sides should be afraid to cut back either unilaterally or even bilaterally, as that would create an incentive for the other side to attempt a secret arms buildup. But that does not mean there is no possibility for future reductions. The rules of the game can be changed.

Suppose, for example, that there is a new technology such that to achieve an attack capability requires five times rather than three times the number of missiles of the other side. The old equilibrium with 50 missiles each gives way to a new solution with 25 missiles for both sides. Even more importantly, both countries have a unilateral incentive to disarm from 50 to 25. The U.S. can safely reduce its missile number to 25 knowing that gain to the USSR from reciprocating is sufficiently large to persuade it to dismantle down to 25 rather than attack at 125.

Even if we are above an arms level commensurate with minimal nuclear deterrence, these types of changes in the technology of an attack capability increase the margin of safety. In our uncertain world, there is never a guarantee of a credible attack capability, nor of having enough for deterrence. Instead, there is a trade-off between the cost of extra weapons and the probability that this is sufficient for deterrence. Strategies that raise the probability that a given level of arms is sufficient for mutual deterrence can make arms reduction talks more effective even when we are far above these minimum levels.

The point of this essay is not to suggest any single agreement or weapons system as being the right way to achieve minimal nuclear deterrence. This theory is meant to provide a framework for discussing defense requirements. By providing a target, it reduces the fear of overstepping the mark. It gives us something to aim for.

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