## THE WORKSHOP

# *Evaluating the Strategic Balance*

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Two issues which have generated large-scale public debate in the last year or two are the SALT II treaty and the decision to deploy the MX missile. Less publicized has been the debate over the requirements for deterrence. Judgments concerning all these questions depend, at least in part, on evaluations of the present or projected state of the strategic balance.

This paper examines several sets of indicators of the strategic balance—spefically, pre-attack, retaliatory and multiple-exchange indicators. I consider both the technical validity of these indicators and alternative formulations of the requirements for deterrence.

Disputes over public policy often turn quickly into disputes over measurement strategies. Each side to the dispute chooses the indicators that best justify its policy preferences. These different measurement strategies are frequently based on different implicit assumptions and goals. When such policy disputes become public debates, there is a tendency to shift to indicators which can be understood best by the public, without publicizing the underlying assumptions and goals. Yet, if policy selection is to be made in the public arena, it is essential that the public be informed about the stakes involved in the choice of measurement strategies. This paper illustrates the role of measurement strategies in policy debates in a particularly crucial area, America's nuclear strength and the strategic balance. The subject involves decisions concerning SALT II, new weapons systems (e.g., the MX), and nuclear strategy.[1]

Any judgment of whether the SALT II treaty (or any other arms-control agreement) is advantageous for the United States will depend, to

[1] Debate on nuclear strategy revived around 1974. This debate focused on both the use of "limited nuclear options" and the strategy for a large-scale war. For some recent contributions on the latter issue see Albert (1976), Hoeber (1978/1979), Gray (1979, 1980), and Richelson (1980).

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a significant extent, on perceptions as to how that treaty will affect the state of the strategic balance.[2] Likewise, the wisdom of deploying the MX or selecting a particular nuclear strategy will be judged, in the first case, on how such a decision affects the strategic balance and, in the second, on whether the chosen strategy is credible in light of the prevailing strategic balance. For it is the state of the strategic balance that will determine, to a significant extent, whether the ultimate objective of each of those decisions—deterrence—is achieved.

There are, of course, several qualitatively different types of action the U.S. would like to deter—a Soviet nuclear attack on the U.S., a Soviet attack (nuclear or conventional) on a U.S. ally, or a Soviet attempt to "Finlandize" a particular nation, to name just a few possibilities. Similarly, to achieve any given type of deterrence the U.S. could threaten several alternative targets: Soviet urban-industrial areas, Soviet conventional military forces, or Soviet facilities crucial to the country's economic and political recovery.

It should not be surprising, given the different types of deterrence and the alternative threats that can be employed, that there are many ways to measure the strategic balance. Alternative measures of the strategic balance, or more precisely of its many aspects, reflect differing judgments about which actions need to be deterred most at a given time and about the most effective way of achieving deterrence.[3] The purpose of this paper is to examine the differences among the various indicators of the strategic balance—not only their technical differences but also the differing views as to actions to be deterred and the requirements of deterrence that underlie them. I consider three main classes of indicators: pre-attack indicators, retaliatory indicators, and multiple-exchange indicators. This division reflects the differing views as to the requirements for deterrence. Within these categories individual indicators are discussed—specifically, I explore whether they adequately measure a particular aspect of the strategic balance. The section on pre-attack indicators also serves to introduce some basic concepts that I use throughout the paper.

[2] Two additional SALT issues often considered significant are verification and "linkage."

[3] While one would expect near-unanimous agreement that a large-scale Soviet attack on the U.S. is less desirable than a Soviet invasion of a U.S. ally, many may feel that the latter needs to be deterred most. In other words, they consider the present U.S. capabilities sufficient to deter a Soviet attack on the U.S.; therefore further addition to U.S. capabilities should be along those dimensions which contribute most to deterrence of a Soviet attack on a U.S. ally.

## Pre-Attack Indicators

Pre-attack indicators attempt to summarize in a single number or index the capability of a nation's strategic nuclear arsenal prior to any conflict. Such indicators therefore represent a nation's first-strike or launch-on-warning capability, rather than its retaliatory capability. Despite the heavy stress on retaliatory capability in discussions of the strategic balance, pre-attack indicators are the most popular measures of the strategic balance, especially in the literature addressed to the general public.

The popularity of such indicators can be attributed to three factors. First, they are easily presentable in tabular or graph form and quickly understandable, as they involve only "greater than" or "less than" comparisons. Second, they are generally easily computed so readers can "see where the numbers come from" rather than depend on someone's interpretation of computer output. Third, and most insidiously, there are enough indices that an individual may select as the basis for argument the index which best supports his or her views as to the need (or lack of need) for specific defense programs. Thus, those who favor greater U.S. spending on strategic forces tend to focus on indices such as megatonnage and strategic nuclear-delivery vehicles (in which the USSR is ahead), while those with opposing views tend to focus on warheads and (until recently) accuracy (in which the U.S. has led).

Another argument for the use of pre-attack indicators involves third-party perceptions of the strategic balance. It is often argued that any great disparity in the relative standing of the U.S. and USSR with respect to certain static indicators will affect smaller nations' perceptions of the relative power of the two countries. It is assumed that an apparent USSR superiority will give that country additional leverage with respect to such nations. Hence, it is often argued that the U.S. must maintain "essential equivalence" with the Soviet Union, an equivalence which would be reflected by pre-attack indicators.

Before considering specific indicators, I should note that a nation's strategic forces can be evaluated on different dimensions, reflecting different missions which these forces might be required to perform. Indicators can be divided into subsets depending on the dimension with which they are concerned. Thus, we will consider three specific dimensions: soft-area destruction capability, hard-target kill capability, and target-coverage capability.

### *Soft-Area Destruction Capability*

Soft-area destruction capability means the capability to subject a large, unprotected area, such as a city, to at least the minimum level of blast overpressure—the pressure created by the blast over normal atmospheric pressure of 14.7 pounds per square inch—required to destroy its unprotected structures (buildings, factories). Such a target contrasts with a hard-point target, such as a missile silo, which has an area of only a few square feet and is protected by layers of concrete.

Two well-known indicators of soft-area destruction capability are megatonnage and equivalent megatonnage. One megaton produces an explosive blast equal to that of a million tons of TNT. To compare two strategic arsenals on the basis of total megatonnage or total yield in megatons one simply adds up the megatonnage of all the strategic warheads and bombs in the nation's arsenal.

The total megatonnage available is supposed to give an indication of the soft-area destruction or "city-busting" capability. A one-megaton blast can subject an area of 20 square miles to a blast of at least ten pounds per square inch (PSI) of overpressure (Sibley, 1977). Such an explosion is sufficient to destroy unprotected buildings in that area. However, while it is true that the greater the megatonnage of a weapon the greater its area-destruction capability, the relationship is not a linear one.

As often noted (Bellany, 1973; T. Brown, 1977), a weapon with $n$ times the yield of another weapon will not destroy an area $n$ times as large —or, more precisely, will not subject an area $n$ times as large to a given level of overpressure. The reason is that, while a nuclear explosion occurs in three-dimensional space, its damaging effects occur along the dimensions of length and width but not of height—since no targets are located solely in the area above the explosion. Hence, the megatonnage directed at the two significant dimensions of the target will be equivalent to the megatonnage of the weapon raised to the ⅔ power.[4] Thus, a one-megaton weapon (i.e., one 50 times greater in yield than the .02-megaton bomb dropped on Hiroshima) would only subject 14 times as much territory to a given level of overpressure: $1^{2/3}/.02^{2/3} = 14$.

Common sense would require that, for any index, a greater value should translate into a greater capability on the relevant dimension. Due to the ⅔-power rule, total megatonnage fails to meet this requirement. For example, one five-megaton weapon would be able to subject $5^{2/3} \times 20 = 58$ square miles to at least ten PSI overpressure, while four one-

[4] Equivalently: the distance from ground zero to a point vulnerable to a specified level of overpressure is proportional to the cube root of yield, and the area affected is proportional to the distance squared. See Collins and Cordesman (1978).

megaton weapons would be able to subject $1^{2/3} \times 4 \times 20 = 80$ square miles to ten PSI overpressure.

To correct this flaw and discount the "wasted" portion of a nuclear blast, the concept of Equivalent Megatonnage (EMT) has been defined. As might be expected from the discussion above, the equivalent megatonnage of a warhead is defined as yield raised to the ⅔ power, whenever yield is less than or equal to one megaton. When yield is greater than one megaton, EMT is often defined (Groover et al., 1978) as yield raised to the ½ power (the rationale for this adjustment is discussed below).

Total equivalent megatonnage is obtained by summing the equivalent megatonnage of each weapon over all weapons. Clearly, the concept of equivalent megatonnage systematically downgrades the influence of large-yield weapons vis-à-vis small weapons. A 25-megaton weapon counts only five times as much as a one-megaton weapon in computing total equivalent megatonnage, as opposed to the 25-times-greater contribution it would make to total megatonnage.

This difference has great practical significance in evaluating the strategic capabilities of a given weapons system or arsenal. Consider the Poseidon SLBM, with its ten .04-megaton warheads. This weapon's total megatonnage comes to less than half a megaton—.4 MT, to be exact. Yet the total equivalent megatonnage of a Poseidon is greater than the EMT of a one-megaton weapon: $(.04)^{2/3}(10) = .12(10) = 1.2$. This difference is also significant in comparing U.S. and Soviet arsenals. Since the Soviets tend to build higher-yield weapons than the U.S., including the 25 MT SS-9, their lead in equivalent megatonnage will be smaller than their lead in megatonnage.

While total equivalent megatonnage indicates area-destruction capability better than total megatonnage, they share one serious flaw. Two warheads, each one megaton (and thus one equivalent megaton) in yield, can subject two widely separated areas of 20 square miles each to ten PSI overpressure. While a single five-megaton warhead will be able to subject more square miles (58) to ten PSI overpressure, the miles must be adjacent—i.e., the damage can be done to only one target. Many cities, even those with a population in the neighborhood of one million or more, are significantly smaller than 58 (or even 40) square miles.[5] Thus the two smaller warheads may subject less territory to ten PSI overpressure but destroy more targets of value (e.g., buildings and factories). Hence, total equivalent megatonnage may overvalue the equivalent megatonnage of some weapons.

[5] For example, Boston and San Francisco.

The adjustment noted above—raising equivalent megatonnage, for a weapon with a yield greater than one megaton, by a factor of ½ rather than ⅔—attempts to compensate for this flaw. This adjustment further downgrades the importance of large-yield weapons—the 25-megaton warhead that contributes five times as much to total equivalent megatonnage as a one-megaton weapon, when yield is raised to the ½ power, contributes 8.55 times as much when yield is raised to the ⅔ power.

Two criticisms of this adjustment can be made. First, it is rather ad hoc and still allows for the equivalent megatonnage of high-yield weapons to be overvalued—the five equivalent megatons of the 25-megaton weapon that are counted are still far more than necessary to subject all but a very few cities (e.g., Los Angeles) to ten PSI overpressure. Second, this adjustment destroys any linear relationship between equivalent megatonnage and the area that can be subjected to a given level of overpressure.

An alternative method of devaluing excess equivalent megatonnage is what I shall call the Distinct Blasts Index (DBI). The value of this index is defined as the maximum number of distinct one-equivalent-megaton or greater blasts that can be generated from a strategic arsenal. Each one-equivalent-megaton or greater blast could be generated from either a single weapon or a combination of several weapons. The selection of one equivalent megaton as the unit of division is justified by the observation that all cities can be either severely damaged or totally destroyed by a one-equivalent-megaton blast at their center. Also, since a soft-area target cannot escape attack, there is no time or warhead constraint—several weapons can be used over a period of days to produce the cumulative effect desired.

Calculation of the value of the DBI index might require the use of mathematical programming methods, if the number of weapon types and their yields vary greatly. However, as a rule of thumb, the DBI value can be obtained by minimizing the sum of excess equivalent megatonnage (equivalent megatonnage over one) for each combination of warheads. As an illustration, consider a strategic single-warhead missile force consisting of four types of missiles with the EMT values given in Table 1.

The DBI value would be 567: 100 one-equivalent-megaton blasts from the 100 $M_1$ missiles, 100 from the 100 $M_2$ missiles, 300 obtained by combining the 300 $M_4$ missiles with 300 of the $M_3$ missiles (one $M_3$ and one $M_4$ per target), and 67 one-EMT blasts from the remaining 200 $M_3$ missiles. In general, use of the DBI should further depress the value of high-yield weapons relative to low-yield weapons. The total equivalent megatonnage of the missile force in Table 1 is 660. Hence, its capability would be ranked higher than that of a missile force of 567 one-megaton

TABLE 1

Hypothetical Missile Force A

| Type | Number | Individual EMT |
|---|---|---|
| $M_1$ | 100 | 1 |
| $M_2$ | 100 | 1.5 |
| $M_3$ | 500 | .4 |
| $M_4$ | 300 | .7 |

weapons on the basis of total equivalent megatonnage but equal on the basis of the DBI.

One could argue that the DBI is a superior measure because, rather than involving an ad hoc adjustment of equivalent megatonnage, it is based on a reasonable estimate of the equivalent megatonnage actually required to attack most metropolitan areas. Additionally, use of such an index allows for complementary use of an unadjusted total EMT index (equivalent megatonnage equals megatonnage raised to the ⅔ power in all cases) so that EMT would be linearly related to the total area which can be subjected to a given level of overpressure.

*Hard-Target Kill Capability*

While the ability to destroy cities and unprotected targets depends primarily on the ability to lay sufficient megatonnage against those targets, the ability to destroy hardened-point targets such as missile silos and command and control centers depends mainly on the accuracy of the warheads. While soft targets can be destroyed by the blast and thermal effects of an explosion, which extend for many miles from the point of impact, hard targets are relatively immune to such effects. Their destruction will result primarily from the high levels of overpressure which occur only in a small area around the point of impact.[6]

These considerations are incorporated in the two equivalent concepts

[6] Hardened-point targets can be destroyed or made inoperative by means other than the level of overpressure. For example, the *duration* of the overpressure (which increases with increasing weapon yield), as well as its strength, can lead to neutralization of the missile. Additionally, piling up of debris on the silo closure, which either makes it impossible to blow off the lid or subjects the missile to damage when the lid is opened and debris falls into the silo, can also neutralize the missile.

known as Lethality ($K$) or Counter Military Potential (CMP).[7] The lethality of a warhead $i$ is defined as:

$$K_i = Y_i^{2/3}/\mathrm{CEP}_i^2$$

where $Y$ is the yield in megatons of warhead $i$, and CEP is the circle of equal probability—the radius, in nautical miles, of the circle in which there is a .5 probability the warhead will land. CEP is thus a measure of accuracy—the lower the CEP the more accurate the warhead.

The probability of destroying a hard-point target is an increasing function of $K$ and a decreasing function of the hardness of the target, where hardness is measured by the overpressure in pounds per square inch (PSI) needed to destroy the targeted silo.[8] Additionally, two independent warheads with lethality $K$ will have the same kill probability as a single warhead with a lethality of $2K$.

To illustrate the relative importance of accuracy vis-à-vis yield in determining $K$, consider that if $Y = 1$ and CEP $= 1$, then $K = 1$. If $Y$ is increased by a factor of 8, we get $K = 8^{2/3}/1^2 = 4$, while if accuracy is increased by a factor of 8 (i.e., if CEP is reduced by a factor of 8), we get $K = 1^{2/3}/(1/8) = 64$, which is a *sixteen*-fold difference in the increase of $K$. In addition to the relatively more crucial role of improvements in

[7] For a discussion of the CMP index see Collins and Cordesman (1978).

[8] There are numerous equivalent formulas for the kill probability ($P_k$) of a warhead against a hardened-point target. The one which makes the most explicit use of $K$ is given by T. Brown (1976) as:

$$P_k = 1 - \exp\,(-f[h] \bullet K)$$

where $h$ represents target hardness and

$$f[h] = \frac{\ln 2}{[.068h - .23\sqrt{h} + .19]^{2/3}}$$

For an alternative formulation see Davis and Schilling (1973).

As indicated above (note 6), the use of $K$ ignores the possible effects of pulse duration in rendering a silo inoperative. The formulations used by Brown, Davis and Schilling, and others are also based on a "cookie-cutter" model. Such a model assumes that there is a lethal radius, $r$, around a target. If a weapon of a particular yield detonates at a distance $d$ from the target, such that $d \leq r$, then the target is destroyed with certainty, while if $d > r$ the target survives with certainty. An alternative formulation, which assumes a continuous probability distribution over weapons-impact points, is used by the Defense Intelligence Agency (1969). The actual differences in resulting probabilities are not of major significance. See Steinbrunner and Garwin (1976: nn. 3, 12) and Davis and Schilling (1973) for more extensive discussions.

accuracy, accuracy's absolute significance should also be noted. If the CEP of a weapon is halved, and in present circumstances this may amount to a simple decrease of .1 nautical mile in CEP, then $K$ will increase by a factor of four.

It should also be noted that if CEP is reduced to values close to zero, the formula will produce very large values of $K$, enough to yield a $.\overline{999}$ kill probability against the hardest targets, regardless of the megatonnage involved. For example, if $Y^{2/3} = .0000001$ and $CEP^2 = .0000000001$, then $K = 1{,}000$, sufficient for a $.\overline{999}$ kill probability against a target hardened to 5,000 PSI—despite the fact that the yield of the weapon would generate less than 300 pounds of overpressure. In other words, for the formula to have any validity, the explosive yield of the warhead must be sufficient to destroy the target when detonated at its exact center. While such paradoxes may not occur in calculations relating to present weapons systems, the introduction of MIRV's and cruise missiles with extremely low CEP's into strategic arsenals will create the possibility of such miscalculations.

The total lethality for a strategic arsenal is simply the sum of the lethality of each warhead, $\Sigma_i K_i$. The problems of using such an index parallel those involved with the use of total megatonnage and total equivalent megatonnage: a nation, the $\Sigma K$ value of whose arsenal is $n$ times greater than that of another nation, does not necessarily have the capability to destroy $n$ times as many hard-point targets.

A corollary of this fact is that, just as with equivalent megatonnage, the capability of a nation to destroy certain targets (in this case hard-point targets) is a function of both the aggregate value of the index and its distribution across warheads. By ignoring this simple fact several authors (Tsipis, 1974, 1975; Rummel, 1976) have produced erroneously reasoned (and directly contradictory) conclusions about the vulnerability of U.S. missiles to Soviet attack.[9]

To illustrate the possible pitfalls in the use of aggregate lethality, consider Table 2. $P_k$ is the probability of a single type $M_i$ warhead destroying a particular hardened-point target. The potential attacker possesses two types of missiles/warheads, $M_1$ and $M_2$, with $K_1 = 100$ and $K_2 = 1$. Suppose there are 1,000 silos to be attacked and $P_k = .97$, when $K = 50$. One might then assert that the lethality needed to destroy 97 percent of the 1,000 silos is 50,000 ($50 \times 1{,}000$) and proceed to determine if aggregate

[9] These conclusions, it should be noted, are based on data different from those which have led to recent concern over the survivability of U.S. land-based ICBM's.

TABLE 2

Hypothetical Missile Force B

| Type | Number | $K$ | $\Sigma K$ | $P_k$ |
|---|---|---|---|---|
| $M_1$ | 500 | 100 | 50,000 | .99 |
| $M_2$ | 500 | 1 | 500 | .05 |
| | 1,000 | | 50,500 | |

lethality were greater than 50,000. If it was, one might argue that the nation with Hypothetical Missile Force B could indeed destroy 97 percent of the 1,000 silos. However, given the data in Table 2, and given that a single warhead, regardless of its lethality, cannot destroy more than one silo (when silos are adequately separated), we would expect that only $.99(500) + .05(500) = 510$ silos would be destroyed. In other words, like excess equivalent megatonnage, excess lethality cannot be "transferred" from one warhead to another. Although this is a simple point, it is exactly the type of error made by Tsipis and Rummel.[10]

At the opposite extreme, consider the situation where a nation possesses 50,000 warheads, each with $K = 1$. This arsenal would yield the aggregate $K$ value required for destruction of 97 percent of the 1,000 silos. However, there is the problem of fratricide. Fratricide refers to the destruction or neutralization of an incoming warhead by a preceding warhead—i.e., the explosion of the first of the two incoming warheads prevents the second from detonating. This situation may result from several factors: (1) if the neutrons produced by the first explosion are absorbed in sufficient quantity by the nuclear material in the following warhead, that warhead may fail to explode; (2) the blast wave created by the first warhead could destroy the second if the second follows too closely; and (3) if the first warhead is detonated at or near ground level, it could eject large particles of debris into the atmosphere, which could destroy an incoming warhead in a collision.[11] Given the lack of real-world experience with such situations, fratricide is obviously a hypothetical/theoretical problem. However, it is generally believed that one can time, at most, a two-warhead-per-target attack adequately enough to avoid fratricide while still getting both

[10] For a further critique of Tsipis' articles, see T. Brown (1976).
[11] For further discussion see Speed (1979, ch. 3).

warheads to the target before a counterattack missile can be launched.[12] Hence, only 2,000 of the warheads, and 2,000 units of lethality, could actually be used; one would expect, assuming perfect reliability, that ten percent of the 1,000 silos would be destroyed.

Clearly, the lethality index can yield misleading results when calculated with either too many or too few warheads. That total lethality be greater than required aggregate lethality is a necessary but insufficient condition for the capability to destroy a given percentage, $\alpha$, of hard-point targets. The necessary and sufficient conditions are that: (1) the kill probability against each target is at least $\alpha$, and (2) this kill probability is achieved with no more than two warheads. These conditions imply that aggregate lethality is greater than required, but not vice versa.

An alternative measure of hard-target kill capability is the PSI Index. As the Distinct Blasts Index is designed to indicate the number of distinct areas that can be attacked by a strategic force, the PSI Index is designed to indicate the number of hard targets that can be destroyed. Also, it is designed to incorporate the third variable which determines hard-target capability. As noted above, while the probability of destroying a hard target is an increasing function of $K$, it is not solely a function of $K$. A third variable, hardness, enters into the equation. The first step in computing the PSI value for a nation is to assign a hardness to the other nation's silos. Since in reality this value can vary with different silo types, the value chosen may have to be a compromise. Once this value is chosen one can compute the kill probability against such targets for each warhead in a nation's arsenal. The sum of these $P_k$ values over all warheads will yield the expected number of silos destroyed.

While the PSI Index corrects one of the basic flaws of the lethality index—that, in effect, it gave a single warhead the capability of destroying more than one silo or other hard-point target—it is still subject to the other flaw. An arsenal with a very large number of warheads, all with low kill probabilities, will on paper appear to have an impressive capability to destroy hard targets. However, since only a fraction of these weapons can actually be used, due to fratricide constraints, the actual capability will be negligible. Additionally, the PSI Index does not distinguish between prompt

[12] Of course, a nation could try to launch its missiles before even the first warheads land. Such a policy is referred to as either launch-on-warning, launch-on-assessment, or launch-under-attack, depending on how quick a response time is allowed. Such a policy is considered extremely risky for several reasons relating to the size of the attack and the probability of warning-system failure. See Wolfowitz (1970) and Garwin (1980) for contrasting views.

hard-target capability, such as ballistic missiles, and slow hard-target capability such as bombers and cruise missiles.

Several adjustments could possibly correct these flaws, but they have problems as well. For example, Groover et al. (1978) suggest the classification of Good Hard-Target Kill Capability, which requires that a warhead have a $P_k$ value of .7 to be counted at all in this index. However, aside from the arbitrariness of selecting .7 rather than .75 or .65, this measure ignores the interactions of warhead combinations. If a single warhead with a .7 $P_k$ value is a good hard-target weapon, why are two warheads, each with a $P_k$ value of .5 and hence a cumulative $P_k$ value of .75, not good? If a nation has a large number of warheads available, assigning a second warhead to each target is quite reasonable and, as mentioned above, technically feasible. Additionally, warheads with low $P_k$ values, when combined with warheads with high $P_k$ values, may contribute just enough to overall kill probability to make a significant difference. For example, a warhead with $P_k = .55$, when added to a warhead with $P_k = .85$, increases the kill probability from .85 to .93—which may often be considered a strategically significant jump.

Another possible adjustment is to separate prompt hard-target kill from slow hard-target kill capability—where the former refers to the capability of missiles which can reach their targets in about 30 minutes and the latter to the hard-target kill capability possessed by bombers and cruise missiles, which take several hours to reach their targets. This formulation would allow separation of the capability that could be used rapidly from that which could not. It is often argued (Galen, 1979) that slow hard-target capability is of little value, since it gives an enemy several hours to reprogram if necessary and to launch missiles. If we are concerned with the capability to launch a first strike, this complaint seems justified. Yet there may be significant reasons why the side being retaliated against would prefer to ride out a counter-attack rather than launch its remaining missiles.[13]

### *Target-Coverage Capability*

A third set of indicators deals with the number of targets that can be

[13] For example, even if Soviet missiles held in reserve as a form of blackmail against unattacked U.S. cities were attacked by cruise missiles, the Soviet leadership might prefer to ride out the attack. This would leave a depleted but still existent blackmail capability of launching such missiles. A premature launch would remove the blackmail capability and result in a U.S. response against Soviet cities.

attacked or destroyed by a strategic arsenal. The simplest of these indicators is the total number of strategic nuclear-delivery vehicles. A strategic nuclear-delivery vehicle (SNDV) may be either an ICBM, SLBM, or strategic bomber (i.e., a bomber capable of attacking the enemy's homeland from the attacker's homeland).

Using the total number of SNDV's as an indicator of target-coverage capability involves counting all delivery vehicles equally. Such an index served at one time as a somewhat reasonable approximation of the number of targets that could be attacked, although it said and says nothing about the actual effectiveness of an attack. Its only distortion prior to 1970 was that it disregarded the fact that bombers carry several bombs. However, with the introduction of MIRVed missiles in the 1970s and the anticipated introduction of cruise missiles in the 1980s, the total number of SNDV's no longer offers a reasonable approximation of target-coverage capability. Thus, as greater megatonnage does not imply greater area-destruction capability, a greater number of SNDV's does not necessarily imply a greater target-coverage capability—it is perfectly possible to have fewer SNDV's but more warheads that can be directed at separate targets, as is the case with the U.S. and the Soviet Union at present.

The cruise-missile factor also indicates the arbitrariness of the definition of a SNDV. A ballistic missile counts as a single SNDV, as does a bomber. But a bomber may carry up to 20 cruise missiles. Should the bombers be counted as a single vehicle or should the cruise missiles be counted individually? SALT II's resolution of this issue is to count the number of bombers containing cruise missiles as MIRVed weapons. However, in the distant future cruise missiles may themselves be MIRVed, further complicating the issue.

An alternative indicator—the total number of independently targetable warheads and bombs—would seem a superior measure of the number of targets that can be attacked. This figure would include the number of independent-missile warheads, cruise missiles, and bombs carried by strategic bombers. A minor flaw of this index is that it does not recognize the restrictions as to which targets a given arsenal can attack. MIRV's carried by the same bus can only be dropped within certain distances of each other—50 miles downrange and 30 miles laterally (Tsipis, 1974). Bomber attacks are restricted to a set of bomber tracks—a bomber cannot attack both Kiev and Vladivostok, for example.

A more significant flaw is that, as with the SNDV index, the indicator says nothing about the effectiveness of an attack. Since the yield and accuracy of the weapons and the nature of the targets and their defenses are not incorporated into the measure we get an idea only of the ability to attack, not destroy, targets.

Payne (1977) has attempted to take these considerations into account and to develop an index which summarizes the ability of a nation's strategic forces to effectively attack an opponent's target system. His index is called the Equivalent Weapons (EW) index. Its value per warhead is defined as:

$$\text{EW (per weapon)} = \frac{1}{a/Pk_1 + b/Pk_2 + c/Pk_3}$$

where:

a,b,c are the proportions of soft-point, soft-area, and hard-point targets to be attacked, out of the total set of targets attacked;
$Pk_1$ is the probability of destroying a soft-point target;
$Pk_2$ is the probability of destroying a soft-area target; and
$Pk_3$ is the probability of destroying a hard-point target.

The EW index is defined as the summation of the EW value per weapon over all weapons. This index then represents the expected number of targets destroyed when warheads are randomly allocated against them, with no more than one warhead per target in the initial allocation.

Payne's definition of $Pk_1$ and $Pk_2$ are worth noting. $Pk_3$ is the standard counter-silo formula. $Pk_1$ is assumed to be equal to 1 since, given present-day values of CEP and $Y$, destruction of soft-point targets is virtually assured. $Pk_2$ is set equal to the EMT value of the weapon. This procedure creates a certain difficulty, since $Y$ may be greater than 1, yielding a $Pk_2$ value greater than 1 in violation of the definition of a probability or a proportion. As an alternative, we might let $Pk_2 = Y^{2/3}$ whenever $Y \leq 1$ and 1 otherwise.

Thomas Brown (1977) has demonstrated that this index could vastly underestimate strategic capability. Brown demonstrates this via the example reproduced in Table 3. Brown assumes 45 soft-area targets, 45 soft-point targets, and ten hard-point targets. The EW index thus yields an expectation that approximately 45 targets will be destroyed. However, a non-random allocation would result in an expectation that 100 targets would be destroyed. Assigning 45 type-B missiles to the soft-point targets, 45 type-A missiles to the soft-area targets, and 15 type-B missiles to the hard-point targets (ten in an initial wave and five to attack the survivors of the first wave) would result in a value of 100.

TABLE 3

Equivalent-Weapons Index Evaluation
of a Hypothetical Force Structure
(from T. Brown, 1977)

| Weapon Type | Number | EMT | $Pk_3$ | EW | ΣEW |
|---|---|---|---|---|---|
| *A* | 45 | 1.0 | .10 | .53 | 23.7 |
| *B* | 60 | 0.2 | .67 | .53 | 21.1 |
| | | | | | 44.8 |

A more sophisticated version of the EW index is the Relative Force Size (RFS) Index developed by Groover et al. (1978), which has been used in the last two annual reports from the Secretary of Defense (H. Brown, 1978, 1979) to summarize strategic capability. The RFS value represents the number of times a given arsenal can destroy a given set of targets to a specified destruction level. It is computed by defining a strategic-force description, a set of target characteristics, some statement of damage objectives, and an allocation procedure. Differences in strategic-force characteristics such as yield, accuracy, force readiness, and ability to penetrate enemy defenses are combined in RFS calculations. Damage objectives are typically stated as the expected fraction of a selected subset of targetable installations (silos, cities, factories) to be destroyed.

Mathematically, calculation of the RFS involves the application of linear programming to allocate weapons to targets in such a way as to minimize the number of weapons required to satisfy the given objectives. This is equivalent to maximizing the number of times the arsenal can achieve the objectives. Rather than describing the set of equations used to calculate RFS, I offer a simple example. Table 4 depicts the crucial variables needed to calculate the RFS value for this example.

Assigning five type-II weapons with $P_k = .8$ ($P_k$ can be interpreted also as the probability of destroying a point target or the proportion of an area target to be destroyed) against the five type-2 targets satisfies the damage objective with respect to type-2 targets. Using all type-1 weapons against five type-1 targets satisfies the damage objectives with respect to five of the seven targets. The question thus becomes the capability of the five remaining type-II weapons against the two remaining type-1 targets. Assigning two type-II weapons to each target satisfies the .75 damage ob-

TABLE 4

Relative-Force-Size Index Evaluation of a Hypothetical Force Structure

| Weapon | Target $P_k$ 1 | 2 | Number of Weapons |
|---|---|---|---|
| I | .75 | .8 | 5 |
| II | .50 | .8 | 10 |
| Number of Targets | 7.00 | 5.0 | |
| Damage Objective | .75 | .8 | |

jective. Thus, 14/15 of the arsenal can achieve the objectives $1/14/15 = 15/14 = 1.07$ times. Hence, the RFS value is 1.07.

Clearly, the RFS index incorporates more factors than do any of the other indices discussed. However, it is not without flaws. By concentrating on the number of times an arsenal can fulfill certain arbitrarily defined objectives, it may overvalue the ability to fulfill certain objectives again and again. That is, being able to achieve the given damage objectives seven times may be of no more value than being able to achieve those objectives twice. One may desire a certain value above 1 as a hedge against uncertainty, but the marginal value of increasing RFS values may decline rapidly.

A prime virtue of the RFS index, which can also, however, be a drawback, is that it can be used to evaluate alternative targeting doctrines and weapons systems capabilities. As targets and/or weapons vary, one can calculate changes in the ability of a strategic force to carry out certain missions. One can ask how changing the target set will affect judgments as to the adequacy of a strategic force and, thus, how many new weapons of what types are needed. On the other hand, the fact that the RFS value of an arsenal can change even if the arsenal does not, because of changed targets and damage objectives, indicates the subjective nature of the RFS value. In other words, an RFS value indicating that a given arsenal can achieve certain damage objectives does not mean that the arsenal can achieve other objectives.

## Retaliatory Indicators

As an alternative to pre-attack indicators one can consider retaliatory indicators, which yield an estimate of a nation's strategic capabilities after attack. Calculations for these indicators will be more complex than for the pre-attack indicators, since it is necessary to use sophisticated computer models to determine what forces will survive a first strike. Assumptions have to be made concerning how many of each type of available weapon will be employed in an attack and against which particular targets, as well as whether the nation being attacked will launch its missiles once it is warned of an attack (see note 12). Frequently the allocation of weapons to targets so as to maximize the value of the attack to the attacker is not obvious.[14]

To illustrate the increased complexity of the calculation, consider Payne's (1977) definition of Retaliatory EW:

$$\text{Retaliatory EW} = \sum_{i}^{\text{ICBM}} N_i \,\text{EW}_i \,\rho \, P_s \,\text{BMAT}\, P_P \,\text{ABM} + \sum_{j}^{\text{SLBM}} N_j \,\text{EW}_j \,\rho \, P_s \,\text{ASW}\, P_P \,\text{ABM} + \sum_{k}^{\substack{\text{Alert}\\ \text{Bombers}}} N_k \,\text{EW}_k \,\rho \, P_s \,\text{BMAT}\, P_P \,\text{AD}$$

where:

$P_s$ BMAT is the probability of surviving a ballistic missile attack;
$P_P$ ABM is the probability of penetrating an ABM system;
$P_s$ ASW is the probability of surviving an ASW attack;
$P_P$ AD is the probability of bomber penetration of enemy air defense;
$N$ is the number of weapons;
EW is Equivalent Weapons; and
$\rho$ is weapons reliability.

Since we now desire to measure the retaliatory capability of a nation, numerous additional factors must be taken into account, as demonstrated by Payne's formula. The offensive power of a nation's pre-war arsenal, which yielded the value of the pre-attack indicators, is now only one element of the equation. The ability to retaliate will be based on three factors, in addition to pre-attack offensive capability: the ability to survive attack; the ability to launch after attack (reliability); and the ability to penetrate

[14] For development of the procedure for such allocation see Lodal (1972).

enemy defenses. The first of these factors is represented by the $P_s$ BMAT (for ICBM's and bombers) and $P_s$ ASW (for SLBM's) terms, the second by the $\rho$ term, and the last by the $P_P$ ABM (for ICBM's and SLBM's) and $P_P$ AD (for bombers) terms.

Retaliatory EMT, Retaliatory CMP, etc., can be computed along similar lines. That is, a set of retaliatory indicators, each parallel to pre-attack indicator, can be defined in a manner similar to the Retaliatory EW indicator. The Department of Defense's annual reports include Retaliatory RFS values based on two different assumptions: that attacks occur when forces are on day-to-day alert or when they are on generated alert. Of course, converting pre-attack to retaliatory indicators does nothing to correct the inherent flaws of particular indicators.

Also, the uncertainties involved in calculating retaliatory indicators are greater than those involved in calculating pre-attack indicators. In the pre-attack situation there will be some uncertainty about yield and CEP reliability (of both enemy forces *and* one's own). These uncertainties will be joined, in the calculation of retaliatory indicators, by additional uncertainties concerning the number of surviving weapons and their ability to penetrate enemy defenses. Of course, if retaliatory capability is considered the cornerstone of deterrence, the existence of these additional uncertainties will not constitute a valid reason for using pre-attack indicators.

The preference for retaliatory indicators reflects the belief that a nation will be deterred from initiating a nuclear exchange if the potential victim's surviving forces would be sufficient to allow a given level of damage to be produced in retaliation. One may base such a belief on one's perception of the potential enemy's decision-makers as extremely conservative (at least in the context of nuclear-war decisions)—as being unlikely to risk even the possibility of an irrational response if that response would be sufficiently devastating to their country.

In evaluating the results of any set of calculations of retaliatory indicator values, one must have some benchmark against which to assess the adequacy of the surviving forces. For example, it was often argued in the 1960s that the Soviet Union would be deterred from a massive attack on U.S. cities if surviving U.S. forces could respond by destroying approximately one-third of the Soviet population and two-thirds of the Soviet industry. Since it was determined that 400 surviving Equivalent megatons would be sufficient for this purpose (Enthoven and Smith, 1972), the Retaliatory EMT indicator was a crucial measure of strategic capability. Secretary Brown has suggested a similar requirement for present-day deterrence of a Soviet attack on U.S. cities—i.e., the capability of surviving

U.S. forces to destroy the 200 major Soviet cities. In this case, the Retaliatory DBI index might be considered crucial in considering this aspect of deterrence.

On the other hand, if U.S. retaliatory policy called for an attack against specific industrial, military, and political power-structure targets in response to a massive (or other) Soviet attack, a different set of indicator values would be more appropriate. For example, if the industrial, military, and political power-structure targets were steel plants, petroleum refining and storage sites, airfields, missile silos, and leadership shelters (which might be hardened to the same extent as missile silos) then indices such as Retaliatory Warheads and Retaliatory PSI would be more appropriate, since the object would no longer be the destruction of a set of soft-area targets but rather of a set of hard- and soft-point targets.

## Multiple-Exchange Indicators

Some would argue that a major flaw of retaliatory indicators is that they ignore the credibility issue—that although a nation might have sufficient forces to inflict severe retaliation for a first strike, the overall balance of forces, and specifically the relative positions of the combatants after an exchange, might dissuade that nation from using its surviving forces. Hence, it is argued, one should compare the relative positions of the U.S. and USSR after a Soviet strike *and* a U.S. response. If one found that one side or the other would have a much stronger position in the post-war world, it is argued, then that nation can be considered to possess strategic superiority. A further argument for such an approach could be that Soviet strategic doctrine stresses a war-fighting/war-winning capability (Ermarth, 1978). Given such a doctrine, it might be argued, the Soviets are most likely to be deterred by the prospects of an unfavorable position in the post-war world.

Nitze (1976a, 1976b) has calculated the relative positions along several dimensions of the United States and Soviet Union after a nuclear exchange in which the Soviet Union struck first and the U.S. retaliated—both against the other's strategic nuclear arsenal. The indices calculated by Nitze were Equivalent Weapons, Megatons, Equivalent Megatons, Warheads, and Strategic Nuclear-Delivery Vehicles and Throw Weight.[15] His results

[15] The throw weight of a missile is the weight in pounds thrown by the last stage of the missile after the booster has burnt out. It includes the weight of the reentry vehicles, MIRV bus, penetration aids, etc., and is considered important by some as an indicator of the MIRV capability of a missile—the greater the throw weight the more MIRV's that can be carried. Throw weight is usually discussed

show a Soviet edge in all indices, beginning in 1978, with the edge in most categories growing larger over the next six years (the end point for his analysis).

The *Department of Defense Annual Report* (H. Brown, 1979) presents the results of calculations concerning the RFS values for the U.S. and Soviet Union after a Soviet first strike and U.S. retaliation. These results, shown in Figure 1, give the Soviet Union an edge, beginning in 1979 and increasing until 1982. At that point the Soviet advantage begins to get progressively smaller until equality is restored in 1986. After that point a U.S. advantage is projected.[16] Jones and Thompson (1978) have made several sets of calculations concerning relative U.S.-Soviet standing on several indices after a nuclear exchange which would involve both counterforce and countervalue elements. Indices used in their analysis include Warheads, SNDV's, Equivalent Megatons, and Megatons.

There are several points worth making with regard to the calculation of military multiple-exchange indicators. First, such calculations involve significant assumptions about the allocation of weapons to targets. While it may be possible, using programming methods, to optimize the value of an attack given a goal to maximize, the appropriate goal may be difficult to determine. Should the objective be to maximize the gap in equivalent weapons, in megatons, or in warheads? This becomes an even more difficult question when one considers that the proper choice is the one which is most likely to deter the potential attacker.

A final dilemma involves the premise that a nation (or more specifi-

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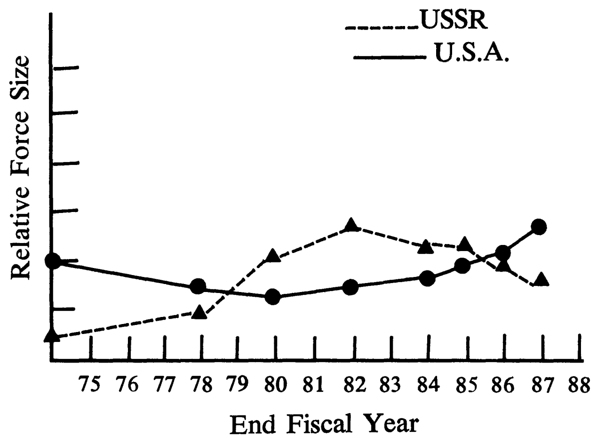
as an indicator of the strategic balance. I have not dealt with it for two reasons. First, it does not fit into any of the three dimensions discussed: soft-area destruction capability, hard-targets kill capability, and target-coverage capability. The second reason, not unrelated to the first, is that throw weight is not truly a measure of the strategic balance. It measures a potential, not a capability that could be used in fighting a war at a given moment. While it might be discussed along with other means for evaluating arms-control agreements, it does not really measure the existent strategic balance in any way. For discussions of throw weight see Kent (1963), T. Brown (1977) and Bellany (1979).

[16] This use of the RFS Index in the Department of Defense's annual reports seems inappropriate. Comparison of the RFS scores of the U.S. and Soviet forces focuses on the wrong issue—the real question is whether U.S. forces can, with reasonable certainty, achieve the specified damage objectives. This question is obscured by the issue of whether the USSR's forces can carry out their mission more times than the U.S. forces can. The latter issue seems particularly irrelevant. If U.S. forces can carry out their mission five times over, does it really matter if Soviet forces can carry out their mission 15 times over?

FIGURE 1

Relative Force Size after Counterforce Exchange




cally, the Soviet Union) will seriously contemplate initiating or risking a nuclear war, or that the United States could be intimidated by the projected relative positions of each nation with respect to the military indicators *after* a nuclear exchange has occurred. Such a premise implies that attainment of such an advantage in a post-war world would be worth the massive costs that nuclear war would involve.

A more reasonable, if still dubious, premise would be that if a significant edge were obtainable in the ability to "recover" from a nuclear war, both in military and economic terms, and absolute recovery time were short (five to ten years), then a nation might be more inclined to risk war if the advantage were in its favor and less inclined if the advantage were not. In fact, until recently U.S. nuclear policy and targeting plans were predicated on the assumption that the most effective means of deterring the Soviet Union was threatening to destroy its economic-recovery base (Speed, 1979; Gray, 1979).

In accordance with such logic, Jones and Thompson (1978) have included in their analysis indices such as Surviving Population, Industrial Capacity Surviving, and Economic Recovery Time. Analysis of such indices for both the U.S. and USSR have been the subject of several government-funded studies (Bickley et al., 1967; Dresch and Baum, 1973).

Calculation of surviving population is based on estimates of both immediate (blast and thermal) effects and delayed (fallout) effects. Surviving capacity can be measured with respect to several alternative indicators: industrial floor-space surviving, the contribution to pre-war GNP by surviving industry, Manufacturing Value Added (MVA) surviving, etc.[17] Recovery time is calculated from the estimates of surviving population and industry employing econometric and input-output models of the entire economy, with recovery time roughly defined as the time required to return the economy to its pre-war level with respect to a given indicator.

Such calculations incorporate an important element of the strategic situation not dealt with by strictly military indicators—that the consequences of a nuclear exchange are related to a nation's nonmilitary assets. Such calculations consequently incorporate factors into the estimates of the strategic balance which were not previously considered: civil defense, industrial hardening, and concentrations of population and industry.

Unfortunately, the models used to translate estimates of surviving population and industry into predictions of recovery time are at a rather crude stage of development. Input-output models do not necessarily perform well even with regard to peacetime economies. Attempts to use them to predict post-war recovery involve the basic assumption that the economic relationships, such as those between sectors of the economy, existing in the peacetime economy will hold in the post-war world. This will further compound the distortions produced. An even greater shortcoming lies in the fact that such models simply assume that the psychological and political consequences of a major nuclear war will not be so great as to prevent recovery, if sufficient means exist to allow such recovery.[18] Hence, conclusions based on such analyses must be tentative at best.

## Conclusions

It should be apparent from the discussion above that measurement of the strategic balance is not a cut-and-dried, technical problem. While the

[17] On the prompt and delayed effects of nuclear war see Lewis (1979). For a discussion of alternative measures of surviving industrial capacity see Richelson (1979). For the method of calculation of surviving capacity see Dresch and Baum (1973).

[18] The technical problems with the use of input-output models are discussed by Ayres (1966). The intangible factors of post-war recovery not dealt with by such models are treated at length in Richelson et al. (1978).

foundations on which the measurement is based are extremely technical (and while some indicators are definitely superior to others), ultimately a great number of judgments about politics and psychology are required in analyzing the strategic balance. Specifically, assumptions about the requirements for deterrence in a given situation heavily influence the choice of indicators. And such assumptions about the requirements for deterrence depend on further assumptions or estimates of the objectives of a nation or its decision-makers and how they will react to certain stimuli.

I have suggested that pre-attack indicators are most appropriate when concerned with the perception of the strategic balance by foreign leaders whose understanding of strategic nuclear issues is very elementary. On the other hand, if deterrence of a nuclear attack on U.S. cities is the main focus, and if one believes that no post-war advantage would compensate the attackers for losses from retaliation, then the Retaliatory DBI or Retaliatory EMT indicators would be most appropriate. Finally, if one believes that a large advantage in either strategic weapons or the capability to recover from a nuclear attack is a significant factor in a nation's decision to initiate war or to accept an increased risk of war, then multiple-exchange indicators would be most appropriate.

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