Title
Strategic defense and the global public good

Journal
Defence and Peace Economics, 15(1)

ISSN
1476-8267 online

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Publication Date
2004-02-15

Peer reviewed

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And the Global Public Good

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Key Words: Missile Defense, BMD, Defense, Security, Conflict, Arms Races, Deterrence, Strategy.

JEL Classification: D74, N4.

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ABSTRACT

To deserve serious consideration a strategic defense system must pass four tests: (1) it must be *technically feasible*. (2) It must preserve the *war avoidance stability* of mutual deterrence. (3) It cannot be so expensive that an adversary can cheaply overwhelm it. (4) It must be *politically feasible*.

Historically, proposed strategic defenses have failed all four tests. But recent changes could make strategic defense prospectively viable if provided as a global public good. Rather than defense to advance individual national interests, universal missile defense to limit damage globally may pass all four tests.

Historically, Mutual Assured Survival has been postulated as a substitute for MAD deterrence. But a global defensive system would mean we can have both mutual survival *and* mutual deterrence.

Economics of Strategic Defense and the Global Public Good

INTRODUCTION

For five decades US security against nuclear annihilation has depended on Mutual Assured Destruction or "MAD," our ability credibly to deter, guaranteeing unacceptable risks of unacceptable retaliatory damage to any potential attacker. Although this strategy has been (blessedly) successful, to the ordinary citizen an ability to protect himself and his family by defeating attack and preventing damage if it is possible, ceteris *paribus* may seem better. An ability to protect against damage with defense reduces one's dependence on the rationality of calculation by an attacker, and may be preferred to an ability to deter attack by promising punishment if only because it feels more secure. This commonsensical argument for protection over deterrence, I believe, is behind government's recurring flirtations with strategic nuclear defense, beginning as early as the 1950's up to SDI-Star Wars of the 1990's. With the turn of a new century the question has returned with an enormous price tag, provoking a familiar clash of rhetoric. Actually this is but another instance of an old problem recurring in the analysis of warfare and strategy: the problem of competition between offense and defense (Boulding 1962, Hirshleifer 2001).

This paper shows how economics provides a powerful organizing structure to assess on criteria of mutual self interest whether, this time or in the mediate future, strategic defense might properly be deployed, or instead whether nothing basic has changed. I want to present the underlying comparative static, economic analysis of deterrence versus defense in a world of strategic competitors who can threaten each other with large-scale nuclear war. In broader terms the analysis will serve as a paradigm more generally to help sharpen thinking about strategy and security.

While the world has changed tremendously in the post Cold War and post Sept 11th era and at the present moment risks of general nuclear war seem remote by reason of U.S. hegemony, permanence of this security is by no means guaranteed. Countries such as Russia, China, and the U.S., might even at present or in the proximate foreseeable future, reliably deliver scores to thousands of nuclear warheads[1], causing destruction in the scores to millions of persons. In years to come one would include India and if it ever so decided Japan (where theater missile defense is now actively considered), and many others.

In the present environment of 2003, war in Iraq, menace from North Korea, and generally diffuse terrorism and threats from rogue states (Sandler and Cauley, 1988 and Sandler and Enders, 2002) are of immediate preoccupation. Nevertheless, missile defense to protect against rogue states, or midget powers although possibly of limited efficacy is not the main subject here. While the analysis might be truncated and applied for that purpose, the framework of this paper is on a larger scale.[2]

Four Criteria for Evaluating Strategic Defenses

The question of missile defense of course is more than a purely operations research or economic question, not simply a question of what weapon systems are best to build. Rather, to make a choice of missile defense is to choose a national strategy. Its adoption would produce momentous change especially if it led us from reliance on "Assured Destruction" to "Assured Survival." This choice belongs in the realm of high policy. But to survive even minimal scrutiny, a missile defense system or indeed any mutation of the present arrangements must pass four tests, tests we shall refer to throughout this paper. These are of course *normative* criteria. I judge them to be evident.

(1) Strategic defense must be *technically feasible*. It must be physically possible simultaneously to acquire large numbers of stealthy in-flight missiles/attacking-vehicles, distinguish them from decoys, and to reliably shoot down practically all of them with our missiles/beams/bullets/electronics etc. Currently there is disagreement among experts whether this may be achievable on a large scale.

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[1] I use the word "missile" to indicate generically bombers, ballistic and cruise missiles, boosters, re-entry vehicles, payload, etc. throughout this paper as the context demands.

[2] Full-scale missile defense applied against small attacks runs at a handicap in a world of smuggling and suicide nuclear terrorism. While strategic defense may protect against very small attacks delivered by missile or bomber, these can be outflanked by surreptitious or unconventional delivery systems. Missile defense on a continental or hemispheric basis seems to be an unreasonably expensive way to protect against very small threats, which can be readily morphed into flanking maneuvers. Although missile defense has been proposed to defeat small numbers of attackers and would likely be capable of this for a small number of attacking missiles, the question remains, quite aside from the "outflanking" argument, of how low scale an attack can be and still be "worth" national missile defense.

(2) It must not overturn *war avoidance stability*. Strategic defense must not undermine the no-attack stability of mutual deterrence --- the delicate balance of terror (Wholstetter, 1959; Schelling 1960).

(3) It must not induce self-defeating *arms race competition*. If an adversary can easily and cheaply overwhelm a missile defense deployment by building more attackers, and if economic and strategic incentives induce an adversary to do so, then missile defense just invokes its own defeat-by-saturation. In earlier days of the Cold War, such competitions might take the form of out and out arms race (McGuire, 1965). But the same principle governs lower level confrontations between economically unmatched adversaries. These are principles of scale, economic feasibility, and incentives.

(4) It must be *politically feasible* and be seen to be in the national and parochial interests of the governing institutions and actors who make or reject decisions and agreements.

Plan of this Paper

In this paper I stipulate that the revolution in smart weaponry, electronics and battle management can some day make large-scale missile defense technically feasible. Technical feasibility is different from economic feasibility. There is always some scale of attack that can overwhelm any defense. This depends inherently on relative cost effectiveness of offense vs. defense --- a point defined and developed later. Engineering feasibility means that now or in some future time period the technical capacity will exist to do all the tasks needed including the ability to defeat countermeasures and to protect the missile defenses against destruction. The paper will then consider the structure of incentives along the second and third of the critical margins, war initiation stability, and arms competition stability. Political feasibility is not seriously addressed.

My purpose is to show how to fit the first and second of the above criteria together in a larger analytic framework [3]. This will lead to a better perspective on why missile defense has failed historically. But it also will identify conditions under which it can succeed in the future. To do this I must build up from war planning, systems engineering, and operations research foundations to a sufficient level of aggregation. This level of generality will then allow application of the tools of economics and the essentials of deterrence theory.

[3] Logically, the fourth criterion is in a different category from the first three. Bad, destabilizing, preposterously expensive systems may conceivably command political assent because some controlling interest benefits. Still, political acceptability is so obviously critical that I include it in my list of minimal criteria.

Strategic Roles and Functions of Missile Defense

Since the subject concerns "missile defense" it seems odd that we must question whether such systems

are actually defensive or instead support attack [4]. As the appendix makes quite clear, however, the question is not at all pointless. Whether missile defense is "defensive" or "offensive" depends on the uses to which it is put, and this in turn depends on its technical parameters as well as the intentions of its owner.

Possibilities for Global Nuclear Defense

As our models identify why large-scale strategic defense was never viable during the Cold War, they necessarily identify conditions under which defense could become viable. Once this is understood I will argue that the new opportunities given to us by technical and political developments (undreamed of at the time of the 1972-ABM Treaty) suggest that we might reevaluate the standard assumption that strategic defense is necessarily adversarial. The reasoning behind this argument is economic. The new opportunity, now or in the future, is for "public good" type collaboration between otherwise-adversaries to make Mutual Assured Survival (MAS) a stable affordable substitute for Mutual Assured Destruction (MAD). The public good argument makes it logical to consider replacing the current reliance on MAD, not with deployment of nation-centered strategic defense, but rather with its renunciation and instead its replacement with global-oriented defense. This would universally reduce potential damage from nuclear war by using defenses not as a measure of partisan advantage but for the global public benefit, which it would create. The technical political obstacles, domestic and international, to such an innovation could be forbidding, and the problems of achieving trusting coordination formidable. But the payoff could be

[4] "Deterrence/defense," "attack/defense," offense/defense": each pair has a different connotation. Add to this "first-strike/second-strike," "damage-inflicting/damage-limiting," "punishment/ protection" and the possibilities for confusion become substantial. Unavoidably, "defense" must bear the burden of diverse meanings, sometimes themselves ambiguous or conflicting. Behind it all is a distinction between the use of forces to survive attack and deliver retribution, vs. to repulse attack and avoid damage. Inherent in the distinction is the idea of an engagement of or duel between opposing forces. The same weapons may serve either or both sides of such engagements, and the ultimate purpose of damage or its prevention may be further damage or protection.

immense. My purpose is not to advocate this, simply to point out that the logic of the models developed here points in this direction.

NUCLEAR STRATEGY, WAR OUTCOMES, SCENARIO DEPENDENCY

Making a choice of nuclear strategy, whatever it is, clearly demands an understanding of which effects of missile defense can be identified as "goods" or "bads" (in the economists' sense of those words) and this in turn requires measures of performance. One primitive input to evaluating defense must be a metric for the outcomes that offensive or defensive forces produce. Basically some measure is needed of the amount of damage in a nuclear war --- quantity, quality, duration --- damage to populations, to industrial productive capacities, and to military forces including an ability to reconstitute and possibly to "prevail." But this raises a problem. Estimates of damage from nuclear strikes/counter-strikes are highly variable, dependent on many unpredictable natural, technical, political, and human factors. All this uncertainty and indeterminacy is summarized in saying outcomes are highly "scenario dependent." Always the effects and incentives introduced by strategic defense will depend on calculations based on some assumed specific sequence of missile/bomber exchanges, attacks and defenses, that is on some "scenario" or more likely on more than one. Examples of such scenarios which planners must contemplate include: (1) an out of the blue, irrational, ill-designed attack by an enemy against our cities, (2) a "well designed" *enemy* first strike to reduce our retaliatory abilities, (3) a mistaken or surreptitious attack, (3) a well designed preemptive first strike *by us*[5], to reduce an adversary's retaliatory capability.

Most often, to give structure to these essentially insane[6] developments some locally"rational" scenario is invented and the damage on each side calculated to represent a "war outcome." Many

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[5] I mean to use "us" and "them" just as a shorthand way to identify two adversaries.

[6] One rational-insane scenario is as follows: a first strike is taken to be *counter-force*, aimed by the attacker against our missiles, bombers, submarines etc, it being assumed that the initiator wants to limit the population/economic/military damage he could suffer from our retaliation. After absorbing this strike the attacked country actually responds (irrationally), possibly with all its remaining strength in a *counter-value* retaliation (which has been diminished or, compromised by the counter force attack which we have already absorbed). And the initial attacker now (irrationally again) responds with all his remaining force to retaliate against our cities. Retaliation would be irrational in the event because (1) reciprocal damage imposed on the enemy actually does the retaliator no benefit, and (2) retaliation wastes the coercive power of the weapons used up in the return strike. This, of course, is

scenarios are postulated and results worked through, a variety of pure or mixed counter force and counter value missile exchanges, all out or partial, rational or irrational, intentional or inadvertent, foreseen or surprise, optimized or ill designed.

Damage Functions and Offense-Defense Missile Duels

Within this maze, economics must organize some general features of the mapping from *forces* to *outcomes* to *preference satisfaction* to help in clarifying choices. Common to all such evaluations is a concept of an offense-defense force duel, and underlying this, estimates of "damage functions" usually made by engineers and operations researchers. We summarize the results of these scenario dependent outcomes, as damage to Country 1 denoted F_1 , and to Country 2, F_2 . Figure 1 illustrates with the case in which Country 1 attacks (or retaliates) against industrial or population targets of Country 2.

The diagram has two purposes. First is to suggest the idea of a wide range of possibilities, F_2 , in Country 2 depending on Country 1's forces (S_1) which actually survive, penetrate, and impact targets in Country 2, *after* various stages of attack-defense. This is pictured as the "damage function F_2." The particular value of S_1 and indeed the entire location and shape of F_2 (S_1) are scenario dependent. Still I approximate it in the diagram as a simple function relationship. It is in their effects on such war outcomes over the entire range of scenarios that any nuclear strategic systems, whether offensive or defensive, are to be evaluated. Importantly, F2 shows *diminishing returns to scale*: more successful attackers produce more damage but at a declining incremental rate. Viewed from the reverse perspective this means *increasing* marginal returns for the defense; more attackers defeated averts damage at an increasing rate. Thus Figure 1 implies a critical importance of scale when assessing deterrence or defense, MAD-forces or MAS-forces. Costs and benefits, which obtain at one scale may be absent, of

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precisely the problem of deterrence, convincing the adversary that one will retaliate in the event, even though it is manifestly against one's interest to do so. See Schelling (1966)."

reduced consequence, or entirely reversed, at different scales of engagement.

Figure 1 Here

Second, Figure 1 suggests the idea that the choice of strategic defenses vs. offensive systems can be visualized as a struggle over the position of the curve F_2 (S_1) and the value of S_1. Country 2 wants the damage curve of Figure 1 to be shifted to the right and twisted downward clockwise. Country 1 --- since it values an ability to punish 2 --- wants damage curve shifted to the left and twisted up-counter-clockwise. For the analogous curve, F_1 (S_2), preferences are the reverse. Thus the conflict between Country 1 and 2 can be viewed as a resource-constrained, scenario-dependent contest over the locations of two such damage functions and the points which would be realized in the event of war.

These combinations of damage outcomes, F_1 and F_2, are to be valued as intermediate products in a larger context by each country --- valued for the risks of intended or unintended war they may cause, for the freedom of action in peacetime which they support, and for the actual losses from an unthinkable nuclear exchange which they represent. We later will suppose, for our heuristic purposes, that each country implicitly adopts a "security or utility index," $V_1 = V_1 (F_1, F_2, Z_1)$ for Country 1 and $V_2 = V_2 (F_2, F_1, Z_2)$ for Country 2, for appraising these outcomes, and combining deterrent, protection, force projection etc. into a single measure. Here Z_1 and Z_2 represent all other relevant factors in the country's "utility function," such as national wealth, public opinion, distribution of income etc.

Figure 1 raises another point. The strategic defense to be considered here confers an ability to *limit* damage, but not to entirely eliminate it. Missile defense may make it physically possible to protect against casualties in nuclear war, which could otherwise number 30% to 80% of population. By "protect" I mean reduce damage to a lesser percentage, 1%, 2%, or 5%, but not to completely eliminate it. The proximate goal of defense would be to reduce damage to such level from a much larger fraction.

Reducing damage below levels of 0.5% or 0.1 % (themselves catastrophic) is in all likelihood simply not achievable since a single thermonuclear weapon can cause more damage than this.[7]

SECOND STRIKE/WAR AVOIDANCE STABILITY

We now come to the second of the strategic/economic criteria proposed earlier, namely war initiation avoidance as a criterion essential to evaluation of strategic defense. Depending on how it is deployed --- cities only, cities and weapons protection, etc. --- strategic defense may have greatly different implications for war initiation stability. (For details see the appendix.) Rather than speculate whether future deployments may be destabilizing (Kent and Thaler, 1989), we will be content to illustrate of how different combinations of war outcomes calculated from missile duels (F_1 and F_2) reinforce or undermine deterrent stability. This will be a world of rational calculating national decision makers. What of a world of isolated leaders, uninformed by intelligence estimates, and preprogramed by ideology? For them perhaps the war initiation avoidance criterion does not apply, but this in no way would strike it as a US criterion for building a defense system.

Consider several symmetric and asymmetric configurations. First can a *mutual bilateral* cost-effective strategic defense be implemented which maintains the reciprocal undesirability of striking first, the dominance of a "wait-don't-shoot" strategy *for both* in a crisis? The answer depends on details of the scenario, but Table I identifies salient cases that at least illustrate stability. It shows % of "national value at risk of loss" in a nuclear exchange for two countries when we can boil the immense complexity and chaos of nuclear crisis down to one scenario: one or the other initiates a war and the other retaliates. Three different symmetric cases are shown; in all three, the two countries, the presence or absence of defenses, and war outcomes between them are assumed to be symmetric. The first row of Table I pictures the stability[8] of Mutual Assured Destruction, which has served for 50 years. Although initiating attack

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[7] Sixty years of nuclear war avoidance has made it uncommon seriously to dwell on the possibility. Yet this essay supposes just such an unthinkable prospect.

[8] A good analysis of this stability, based on Ellsberg's (1956) "critical risk" can be found in Brams and Kilgour (1988).

results in much lower loss than retaliating, still it is so costly to the initiator that in a crisis he will prefer to wait, taking a chance that the adversary will not initiate. Since both sides make the same calculation, both wait and war is avoided.

Table I here

Next consider Row 2; it illustrates a bad, destabilizing strategic defense which capsizes MAD and demolishes the stability of deterrence. Row 2 follows when missile defense reduces damage to initiator and retaliator about equally. This, in effect, is a missile defense system with a comparative advantage tilted toward a first strike and it fairly represents the argument against ABM. Compared to Row 1, the missile defense of Row 2 reduces damage by 19% under both 1st and 2nd strike use ([20-1] = [60-41] = 19). Even though 1% damage is an unprecedented catastrophe, 41% is so much more incomparably worse that both parties may find the incentive to choose the lesser bad irresistible. Finally Row 3 shows a good missile defense, one that enhances stability by eliminating the differential advantage of shooting first. In fact Row 3 makes "wait-don't-shot" an absolutely superior decision rule[9] so that waiting is better even if the opponent decides not to wait and no critical risk calculation (Ellsberg, 1956) is needed. Strategic defense that achieves this would have satisfied the second of our four criteria. To produce a result like this, a missile defense system must perform absolutely and relatively better against an enemy surprise 1st strike, than it would against an enemy's retaliatory response (which would already have been depleted by "our" 1st strike). Although such a defensive system which actually enhances deterrent stability may seem utopian, I later argue that collaborative global missile defense could do just this.

Now consider a notional case where the outcomes are not symmetric, a more realistic case, which might at a time concern the Russians or the Chinese. In Table II the "Stronger" Country represents say the US, and the "Weaker" Country, say China, or Russia. Row 1 indicates how MAD keeps working even under asymmetry so long as there is no missile defense; the loss even when striking first is so great (5%)

[9] If the side, which initiates must expend more of its own missiles to disarm a target than it kills (account being taken of BMD on both sides) then striking first can amount to unilateral disarmament (partial) and produce such results.

that the stronger country will wait in a crisis. But row 2 shows how defenses can be destabilizing. *Only the stronger country deploys a missile defense* in Row 2; and this raises its incentive to strike first in a crisis because 5% is so very much more devastating than 1%. This illustrates why a unilateral strategic defense deployed by the stronger country gives it far more latitude in its "power projection" in pursuit of its foreign objectives to be aggressive or provocative short of nuclear threat --- a situation which Chinese and Russians alike must reasonably dread. If calculations were to show estimates like row 2 then strategic defense will be destabilizing

Table II Here

and should be rejected. However much US policy makers protest as to US intentions, the incentives are there for adversaries to see. If the focus shifts away from rational decision-making based on reasonable calculation and toward ideology driven spasm-war, issues of war avoidance stability recede, to be replaced by absolute protection against suicidal attack.

ARMS RACE INTERACTIONS AND MISSILE DEFENSE

We now come to the third criterion for evaluating missile defense, whether it would cause a reciprocally neutralizing, mutually self-defeating arms race. As we shall see, even dramatic economic disparities between adversaries will not necessarily protect the richer one from a pointless waste of resources; while on the other hand, some relative cost configurations could induce all countries to choose mutually acceptable MAS.

Forces-duel interactions between attack and defense represent a huge systems engineering problem, the business of operations research and other engineering specialties. Economics will contribute to a larger understanding of the reciprocal incentives of adversaries only if we simplify and compress, assuming numerous engineering optimizations to be designed into force structures. For example, to avoid overwhelming complexity, we will focus down to a single principal scenario of nuclear war, and assume we can use known unique damage functions. I want to show how the relative cost-effectiveness of attack-versus-defense should be integrated into economic models of strategic competition.[10] Relative cost effectiveness may determine arms-race-like stability or instead can lead to unstable or self defeating strategic interactions between adversaries. We collapse offensive and defensive forces into a small number of variables effectively suppressing many detailed, elaborate sub-optimizations going on in the background.[11]

Offense-defense force interaction or force conflict functions show the "guaranteed" damages to Country j, i.e. F_j, that country k could promise with S_k reliable, penetrating, impacting warheads. $F_j = F_j (S_k)$. We emphasize that these "offensive" k-forces of must have successfully passed through j's defenses, D_j. We show this forces-duel competition with the relationship $S_k = \varphi^k (A_k, D_j)$. Thus $\varphi(A, D)$ --- which I title "the force-duel function" --- represents the offense-defense interactions (including missile or bomber-air-defense duels) between opposing forces. Here attacking and defending forces have been aggregated and weighted by prices into indices, so that A and D respectively can also stand for expenditures. With $\varphi^k_k = \partial\varphi^k/\partial A_k$ etc. we assume: $\varphi^k_k > 0$; $\varphi^k_j < 0$; $\varphi^k_{k\,k} < 0$ [12]; $\varphi^k_{j\,j} > 0$; $\varphi^k_{k\,j}$ >=< 0.

Next, we combine or merge the force-duel-functions φ with the damage function $F_j = F_j[\varphi^k]$. This allows us to picture the basic strategic allocation problem faced by each of two adversaries in a diagram; importantly we can depict the crucial importance of any *intrinsic economic advantage* of

[10] Jack Hirshleifer points out the possibilities for nesting the attack-avoidance game as a sub-game on which an arms race resource allocation game builds. A start on this has been modeled by Intriligator (1975).

[11] For example, an optimal mix between submarine based, surface based, and air launched offensive weapons is assumed, or between boost phase, ballistic trajectory, and terminal re-entry phase defenses. I ignore details in such optimizations due to scenario dependency (e.g. warning time, variations in target engagement procedures etc.).

[12] This assumption could be questioned: in terms of missile survivability (against an enemy missile attack of fixed strength) returns to defense expenditures are increasing (McGuire 1965 pp 85-6). Anyway, I assume this is overcome by diminishing returns in the damage function $F_j (S_k)$

damage infliction over damage prevention/limitation (or vice versa) as reflected in the combined $F_j[D_j, A_k]$ [13].

To illustrate this idea Figure 2 shows the conflict between countries 1 and 2 over the value of $S_1 = \varphi^1(A_1, D_2)$ and, therefore, of $F_2(S_1)$ --- that is, the damage to Country 2, $F_2 = F_2(A_1, D_2)$. Values of A and D show both physical quantities of offense and defense weapons systems, and dollar outlays. For each combination of offensive and defensive outlays (A_1, D_2) a particular value of S_1 and of $F_2(S_1)$ is identified. Each curve in the right 1st quadrant resembles one of the damage functions[14] of Fig. 1. A different damage function obtains for each value of D where $D^2{}_2 > D^1{}_2$. When D_2 is large the effectiveness of Country-1's offensive forces is reduced. Therefore, curve $D^2{}_2$ lies below curve $D^1{}_2$. The slope of any one curve in the right panel shows the marginal effects on the missile duel outcome of incremental allocations to offense, combined with the consequent incremental increase in F_2. Thus the slope of the "payoff to offense curve" in the right panel is given by $[\partial F_2/\partial\varphi^1][\partial\varphi^1/\partial A_1] = F_{21} > 0$.

Figure 2 Here

The same technical engineering information is shown in the left panel. Curve $A^3{}_1$ shows how the defender's missile defenses D_2 *reduce damage* when A_1 is low. On the other hand, $A^1{}_1$ shows the damage limiting effectiveness of Country-2's defenses when they must deal with a large attack force: $A^1{}_1 > A^3{}_1$. The slope of the "payoff to defense curve" in the left panel is given by $[\partial F_2/\partial\varphi^1][\partial\varphi^1/\partial D_2] = F_{22} < 0$. The offensive and defense effectiveness curves on the two sides of the figure are technically redundant. Embedded in both panels is the force-duel function φ, shown by the dashed lines connecting equivalent curves and points.

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13 These are extensions of missile exchange/defense processes partially developed in McGuire (1967, 1992)

14 The curves in Figs. 2 and 3 assume that both defense and offensive targeting are optimized. This usually leads to a linearization of the damage curves in the right panel. Optimal defense establishes a "price" or constant unit effectiveness for the attackers payload for all value-targets actually attacked. This detail is not pictured.

However, in a contingent behavioral sense the right and left panels are not redundant; choices of A and D made by each country follow from the typical indifference curves which are independent. Country 1 places a positive value on an ability to damage Country 2 but of course a negative value on the cost A_1; thus the shape of these curves in the right panel (indifference curves increasing in the direction of the arrows). Similarly, Country 2 places a positive value on reducing F_2, and a negative value on costs D_2. That is, the indifference curves in Figure 2 give truncated versions of V_1 and of V_2. Tangency points in the right panel how Country 1's choice of A_1 given Country 2's choice of D_2, and in the left panel tangency points show 2's choice of D given 1's choice of A. A similar picture would show country 1's and 2's interaction over the value of $S_2 = \varphi^2(A_2, D_1)$ and therefore over F_1. The two diagrams (competitions over F_2 and over F_1) then would be highly interdependent both with respect to preference functions and to "production" functions.

Figure 2 also highlights an important economic distinction between offensive and defensive expenditure (respectively A and on D considered as dollar expenditures) --- differences in their income and substitution effects. Begin by considering the "defender" in the left panel. There, on the left, greater offensive expenditures (A_1) by Country 1 change the position and slope of Country 2's downward sloping "damage limiting function." First this causes direct *negative income* effects for Country 2 (shifting the function upward to the NW). This income effect of A_1 is obvious from the left panel of Figure 2 where $A^1{}_1 > A^2{}_1 > A^3{}_1$. As A increases it raises F_2 and therefore pushes Country 2 in the left panel northward, which is the negative income effect: if F_2 is a normal "bad" for Country-2, then the income effect will increase its demand for D_2. Second, the effect of greater A_1 is to produce *positive productivity or "price"* effects (making the damage reduction function steeper). Thus offense outlays by Country 1 *increase* the marginal productivity of defensive outlays D_2 ; that is they reduce the marginal price of defense.[15] Since the defense effectiveness curves --- or damage limitation curves --- of the left panel increase in slope when moving up along any vertical slice for given D_2, the marginal product of D_2 increases with greater A_1 which stimulates more D_2. Thus, for the defender, both price and income effects of the adversary's offensive-deterrent force reinforce each other to stimulate defense. Now consider Country-1, the "attacker." In the right panel of Fig. 2, greater defensive outlays (D_2) by Country 2 have *negative income effects* for Country 1 moving its damage-creating curve southward in the right panel. If F_2 is a normal good for Country 1 this shift stimulates more A_1. But increases in D_2 also create *negative price effects* for Country-1 lowering the marginal productivity of A_1 in imposing damage or *raising the price* of damage imposition, and this tends to reduce Country-1's choice of A_1.

Therefore, to summarize: for the offense, price and income effects tend to offset each other, while for the defense they reinforce each other. The price effects of offensive forces tend to stimulate defensive expenditures fueling an arms race, while in contrast the price effect of defensive expenditures is to curtail offensive outlays thereby tending to dampen any arms race. Income effects, by contrast stimulate strategic military expenditures on both sides. This means that first order income effects should tend to exacerbate an arms competition, but price effects are ambiguous and may dampen it. (A more complete characterization of these effects must include simultaneous competition over both F_2, and F_1 discussed below.)

The Offense-Defense Force Neutralization Map

Not only must missile defense be feasible technically, and supportive of no-war-initiation stability, for serious consideration it must be financially sustainable--- the more so especially as between

[15] This is quite a general phenomenon I believe, although often buried in the tremendous detail of operations analysis of strategic budget and targeting.

countries[16], which are approximately economic and technical equals. One crucial factor in comparisons between Mutual Assured Survival and MAD will be the technical-economic comparative advantage of offense vs. defense. The relative advantages of offense over defense has been a subject of lasting interest among analysts. This factor has been suggested as determinative of battle outcomes over history[17] (Lanchester 1916, Deitchman 1962, Levy 1984) as a principle for organization of military forces (Read 1964). The importance of this effect is often overlooked in the chaos of detail re missile defenses, but it is crucial. We can use Figure 2 as a foundation to model this effect. To look closer, consider a plot of the total system cost of imposing a level of punishment or damage on another country *versus the cost of defeating* this damage capability by an optimal combination of defensive systems including missile defense. Here all the numerous roles strategic defense might play in deterrence and damage limitation are collapsed into a direct competition with attacking missiles. The relative performance and cost of forces is already contained in Figure 2.

To extract this information for focus, go back to Fig. 2 and, for a fixed value of $F_2 = F_2^0$, draw a horizontal line. In either quadrant (or both), read off combinations of D_2 and A_2 consistent with F_2^0 and plot these as D_2^0 vs. A_2^0. Then choose another value of $F_2 = F_2^*$, and plot D_2^* vs. A_2^*. Figs. 3a and 3b show this plot, telling how offensive and defensive expenditures compete, just offsetting each other at various levels of damage. That is, they picture the relative effectiveness of offense vs. defense expenditures tradeoff --- summarizing selected information from Fig. 2 and making explicit how much strategic defense outlay is required to neutralize, (or override) $1 of expenditure on deterrence. They show not only the absolute ratio, but also marginal ratios as the slopes of the F_2 contours. (In Figs. 3a/b only damages to Country 2 are considered; another set of diagrams with F_1 contours would be required to show offense-defense competition over damages to Country 1). Most importantly, Fig. 3 also shows that

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[16] Although Russia emerged from Communism impoverished, its nuclear capabilities are still powerful and terrifying. In a world of 10 times or 100 times overkill meaningful "technical equality" can continue to apply.

[17] For example, the grueling trench warfare stalemate of WW I is often attributed to the ascendancy of defense.

the "Offense/Defense Neutralization Ratio" depends significantly on the level of damage. The marginal cost advantage for the attacker is higher at lower damage levels.

A Cost-Effectiveness Structure that Favors Offense: To illustrate Fig. 3a assumes that when the damage level is 40%, at the margin the offense can neutralize $2 of defense expenditure (D) by increasing offense (A) by $1. And when damage level is 10%, the offense can offset an incremental defense expenditure of $5 with an increase in A of only $1. So the diagram plainly shows how in the competition between offense and defense there is a techno-economic *dis*advantage to defense, which systematically *increases* (from 2:1 to 5:1 in our example) the *higher* the level of safety/protection sought by the defender. In a techno-economic

Figure 3a Here

environment like this, strategic defense realistically may only "limit" damage to say 40% casualties, a performance so pitiful it may not be worthy of the name "defense" at all, and probably not worth undertaking. And if it were under-taken at an "acceptable" level, say 5%, even a relatively poor adversary could easily and cheaply defeat it.[18]

Cost Effectiveness Structure that Favors Defense: Figure 3b then shows a contrary configuration. There, the marginal offsetting cost Neutralization Ratio *favors defense*, such that for a damage level of 10% it is *offense* that must match defensive outlays 3:1, while at a damage level as low as 2% this falls to only 1:1. This suggests that with a techno-economic structure such as reflected in Figure 3a, missile defense is likely to be unsustainable. It is so cheaply defeated that deploying it will invoke an easy neutralizing response from the adversary: a futile offense-defense arms race.

Figure 3b Here

On the other hand, a structure such as Fig. 3b makes it financially feasible to pursue defense over offense. Disparities in wealth and relative technical capabilities between adversaries are of course

[18] These "iso-damage contours" and "Neutralization Ratios" are based on detailed elaborate sub-optimizations in force compositions and targeting. Details depend on unit costs of various sub-systems, relative effectiveness, and on the scenarios analyzed; still numerous studies (Kent and Thaler, 1989) show the general sort of relationship pictured in Fig 3a/b.

relevant as well; asymmetries may offset some disadvantages of one security posture over another. But even considering this last factor, a sustainable missile defense requires a technical structure, price structure and therefore a cost structure more like Fig. 3b's over that of Fig. 3a. Thus, the third precondition for strategic defense: only when new missile defense technologies now or at some future point in time incorporate an economic advantage for defense along the lines of Fig. 3b is it reasonable to consider deployment. One reason for rejection of ABM/BMD in the 1960's, '70's and '80's was just such a persistent cost disadvantage (Kent 1964).

Effects of Scale: The curves drawn in Fig 3a/b omit differential effects of scale, and these could be quite important. Quite possibly these iso-damage contours will bend systematically as one moves NE in the direction of greater total scale of expenditures, A+D. For example, they might all systematically increase in slope indicating that greater scale uniformly favors defense over offense more and more as scale increases. Or they might all decrease in slope becoming flatter and flatter at greater scale, which would indicate that increases in scale favor offense. But scale economies or diseconomies might not have these uniform effects. Instead greater scale could cause all the iso damage contours to converge toward some point, or to splay out and diverge indefinitely.

Offense-Defense Arms Race Equilibria: Levels of Armament

Although our description of the strategic competition is only partial, still it represents an interacting bi-national system. At a general heuristic level we now reintroduce into the analysis each country's security or utility function defined earlier as $V_1 = V_1(F_1, F_2 ...)$ and $V_2 = V_2(F_2, F_1...)$. Each country must allocate resources subject to its own resource constraint, and to the technical and production constraints given by $\varphi^k(A_k, D_j)$ and $\varphi^j(A_j, D_k)$, $F_k = F_k[\varphi^j]$ and so on. Although a complete description of bilateral equilibrium is too complicated to be of benefit here, one can still illustrate the beginnings of an international equilibrium and how its equilibrium properties depend on the relative effectiveness and cost of offensive versus defensive systems.

Starting with the simplest case, consider the bilateral equilibrium between Country 1 and 2 implicit in Figure 2. This pictured interactions only with respect to A_1, D_2 and F_2. Now we limit other non-defense uses of resources to consumption (C_1, C_2). The other interdependent variables A_2, D_1, and F_1 are ignored. Thus, we truncate V_1 to $V_1(F_2, C_1)$ and V_2 to $V_2(F_1, C_2)$. We can then picture how the two utility maximizing adversaries will choose values of (A_1, D_2), Q_1 and Q_2. Assume Nash-Cournot behavior. Fig. 4 shows the naive Cournot reaction curves of both countries with respect to these two variables. These have been derived from Figure 2 after indifference curves (in the right panel for Country 1, in the left panel for Country 2) have been extended throughout Fig. 2, tangency points recorded etc. Tangency points in the left panel of Fig 2 generate the reaction function R^2, and tangency points in the right panel generate R^1. For example choose a value of D_2 and therefore a curve in the right panel. A_1 is then determined at the tangency between this curve and the truncated utility function $V_1(F_2, C_1)$. R^1 is the locus of all such points.

The space in Figure 4 is offensive force (A_1) vs. defensive force (D_2). Since A_1 and D_2 represent both quantity of offense/defense and aggregate expenditures on each, we can visualize the axes of Figure 4 as measured in $ so that $A_1 = Q_1 - C_1$ and $D_2 = Q_2 - C_2$. The Cournot reaction curve of the attacking (or counter-city retaliating) country, Country 1, is shown as R^1 --- again, derived from the right panel of Fig.2. Along R^1 damage to Country 2, F_2 , is increasing in the direction of the arrow. Damages to Country 2 increase with greater A_1 and less D_2. For Country 1 along R^1 the more F_2, the better. (R^1 curves backward because of ordinary income and price effects from the right panel of Figure 2). Along R^2 less F_2 is better. Cournot-Nash equilibrium obtains at the intersection of the reaction curves (neglecting interactions between F_1 and F_2) and depends on the positions of the two reaction curves.

Figure 4 Here

Now (still ignoring interactions between F_1 and F_2) we can give an idea of how a change in relative costs of defense vs. attack can change the Nash equilibrium between offense and defense. In Figure 4, if strategic defense is relatively expensive the defending country's (Country 2's) reaction curve R^2 is out to the right. Equilibrium in this case occurs at $D_2 = 0$, and $A_1 = A_1*$ and there is no strategic defense. Next let the relative cost of defense *decline* so that the damage limitation functions in the left panel of Fig. 2 become steeper. This causes R^2 in Fig. 4 to shift in and a new equilibrium results with less damage to 2, greater defensive effort ($D_2 > 0$) and more or less offense, A_1 >=< A_1*. Given ordinary price and income effects, the change in equilibrium following cheaper defense may entail an increase in offensive expenditure, but the level of damage in the event of war will assuredly decline. (Interaction between F_2 and F_1 is ignored).

Because in Fig 2 income and price effects work in the same direction for the defending country, in Fig. 4 Country 2's reaction curve $D_2 = R^2(A_1)$ is drawn with a positive slope throughout. But as previously explained income and price effects conflict for the offensive Country 1. Therefore, I have shown a region of high defensive outlay (above and left of the point of vertical slope of R^1) where an increased price of offense lowers offensive expenditures.[19] Suppressed from this representation of equilibrium is a simultaneous interaction over choices of $F_1(S_2)$. To show this result another pair of figures similar to 2 and 4 would have to be drawn and merged. The combined offense/defense equilibrium in *both* countries then would entail values A_1*, D_1*, A_2*, and D_2*. To find (A_1*,D_1*) solve equation (1). A symmetric maximization gives (A_2*,D_2*).

$$\max_{A_1, D_1} V_1 [F_1, F_2, C_1] \qquad (1)$$

[19] Although the pictured equilibrium is stable, shift the R^2 curve right, and a new unstable equilibrium may emerge.

subject to $A_2 = A_2^*$, $D_2 = D_2^*$, $C_1 = Q_1 - A_1 - D_1$, and

$$F_1 = \varphi^1(A^*_2, D_1), \text{ and } \; F_2 = \varphi^2(A_1, D^*_2).$$

Offense-Defense Arms Race Equilibria: Choice Between Offense and Defense

Short of the complete solution to the maximization problem above, further partial analysis can show how relative costs of defense vs. offense fit together. To do this reassemble information such as contained in Fig. 3 or 3b for both countries. Although the individual graphs like Fig. 3 picture the individual choice of both F_1 and F_2 in each country, they do not show how an overall budget constraint forces countries to choose *between* Assured Destruction and Damage Limitation. Adversaries choose between F_1 and F_2 by allocating outlays between A and D. Fig. 5 gives the entire range of aggregate budgets and of possible allocations between A and D for each country together with the resulting war outcomes as measured by F_1 and F_2. It gives the possibilities for both offense and defense together for both countries.

Figure 5 Here

Thus Fig. 5 pictures the relative effectiveness of deterrence vs. defense expenditures, by making explicit how much defense outlay is required to neutralize or override a $1 of expenditure on deterrence and it does so for both countries at the same time. (Damage levels F_1 and F_2 increase in the direction of the broken arrows.) In both countries the marginal cost ratio for the attack/offense increases for lower damage levels as explained earlier. Each country's naive Cournot problem is to choose a value of $M (i.e. military expenditure equals total resources minus consumption or $M = Q - C$) and an allocation of that amount between A and D, *given that the other side has made an analogous choice*.

Fig. 6 extends Fig. 5 to show how this choice between offense and defense depends on each side's *preferences between* F_1 and F_2. To read Fig 6, start with a given fixed military budget on each side, i.e. M_1 and M_2. Next assume a given division of M_2 into A_2^* and D_2^* in country 2; country 1 is then free to choose between values of A_1 and D_1 provided these sum to $A_1 + D_1 = M_1$. Suppose first that strategic defense is relatively ineffective and expensive compared to offense. For the assumed combination of fixed military budgets on both sides, the set of choices open to country 1 *if the opponent has already made a choice of A_2, and D_2* is shown in Figure 6a as the flat opportunity set. I have labeled this B_1. Thus Fig. 6 traces out the F_1-F_2 options for Country 1 when in Fig. 5 Country 1 travels along one of its military budget lines M_1 and A_2, and D_2 are fixed. That is B_1 in Fig.6 shows the options open to Country 1 when its *own budget is fixed*, and the adversary's choices have already been decided.

Figure 6a Here

B_1 is flat because for given M_2, *and* A_2, *and* D_2 it is easy and cheap for Country 1 to increase damage F_2, (i.e. F_{21} is great) but difficult and expensive to reduce damage F_1 (i.e. F_{11} is small). This curve, B_1, is just one out of a matrix of many combinations of F_1 and F_2 when M_1 and M_2 are varied. For each combination of M_2, A_2 and D_2, by allocating the fixed total of M_1 between A_1 and D_1 , Country 1 can trade off F_1 and F_2. The analogous choices open to country 2 also are shown in Fig. 6a as the steep opportunity set. That is, supposing M_1, A_1, and D_1 are all fixed, then Country 2 can trade off F_1 and F_2. I have labeled this curve B_2 (budget constrained opportunity set for country 2) and this is steep because when missile defense is ineffective or relatively expensive, it will be cheap and easy for Country 2 to increase F_1 damage to its adversary (F_{12} is large), but expensive to reduce damage F_2 to itself (i.e. F_{22} is small)[20].

Suppose for illustration that over some range these marginal productivities Fjk are constant. Then the equation for budget opportunity line B_1 is say $K_1^* = \alpha_1 F_1 - \alpha_2 F_2$. Along this contour, linear for simplicity, the opportunity cost of an increment of defense (lower F_1) to Country 1 is $-\Delta F_1 = -(\alpha_2/\alpha_1)\Delta F_2$

[20] As before these marginal productivity measures F_{kj} combine both relative effectiveness of offense vs. defense in the forces duel function, $S_j = \varphi^j(A_j, D_k)$ and the country's vulnerability given by the damage function $F_k = F_k(S_j)$. For example $F12 = [\partial F_1\{\varphi^2\}/\partial\varphi^2][\partial\varphi^2(A_2, D_1)/\partial A_2]$.

$= (F_{11}/F_{21})\Delta F_2$. This shows that the strategic opportunity cost, within a fixed total military budget (and neglecting any response from the enemy) of improving defense (reducing F_1) by an increment is an incremental *reduction* in F_2 or the ability to punish an adversary. Similarly for Country 2, assuming M1, A_1, and D_1 are all fixed, Country 2's opportunity set, with a fixed budget B_2, is given by say $K_2^* = \beta_2 F_2 - \beta_1 F_1$. Now the marginal opportunity cost of increasing damage to the adversary (Country 1) is given analogously by $-\Delta F_1 = -\beta_2/\beta_1 \Delta F_2$. If its budget is fixed, Country 2 must accept more damage for itself to impose greater punishment on Country 1, so that in this linear case $-\Delta F_1/\Delta F_2 = F_{12}/F_{22} = \beta 2/\beta_1$.

Each country in the anarchy of international politics must decide on how much to allocate to strategic offensive and defensive forces altogether, and how to divide this optimum budget between offense and defense. For a given $A_2^* + D_2^* = M_2^*$, and a given M_1^* how does Country 1 decide on A_1 and D_1? Our earlier definition of a utility function was $V^k(F_j, F_k, C_k)$, where we focus on consumption as the only value other than security. Utility is to be maximized over A_k and D_k given the adversary's choices of $A_j^* + D_j^*$ and k's overall resource constraint of $Ak + pD_k + C_k = Q_k^*$. Here the price variable p is assumed to equal unity.[21] First order conditions will then be $F_{jk} / F_{kk} = V^k{}_k / V^k{}_j$. When country J's allocations are held constant, the term on the left gives country K's marginal rate of transformation, MRT, between F_k and F_j, that is the marginal cost of increasing F_j, measured by the required marginal increase in damage F_k. Thus at an optimum choice, this MRT equals country K's MRS, its subjective marginal rate of substitution between own and enemy damage.

Each country's best choice occurs at a tangency between an indifference curve and an opportunity set Bk. If country 1 changes its mix of A_1 and D_1 this presents Country 2 with a new budget-opportunity set B_k and a new best choice. R_2 is the locus of all these best choices. Fig. 6a gives one of

[21] Consistent with indifference curves of ordinary shape and diminishing MRS between S_k and S_j we assume (where $V^k{}_k = \partial V^k/\partial S_k$, $V^k{}_j = \partial V^k/\partial S_j$ and so on): $V^k{}_k > 0$; $V^k{}_j < 0$; $V^k{}_{kk} < 0$; $V^k{}_{jj} < 0$.

these outcomes as a tangency point at a Cournot-Nash equilibrium point, γ, where both countries' choices are compatible. To complete the picture Fig. 6b indicates how this Cournot-Nash outcome is identified. The reaction functions R_1 and R_2 (different from those of Fig. 4) are drawn in and intersect at point γ. Unlike Fig. 4's ordinary reaction functions, in Fig. 6 the abscissa and ordinate are not individual (country) choice variables. Instead, each country's choice is a linear combination of F_1-F_2 along its opportunity curve B_k. When offense is cheap and defense is expensive it follows as in Fig. 6a that $\beta_2/\beta_1 > \alpha_2/\alpha_1$ and, therefore, the Cournot outcome leaves open unexploited utility gains shown by the lens between indifference curves. Thus the conclusion: when technology and cost favor the attack, the naive Cournot equilibrium of a duopolistic arms race competition tends to an over-provision of offensive weapons providing deterrence, and an under-supply of defensive expenditures to reduce damage if deterrence fails. The contract curve of mutual tangencies (not drawn) inside of point γ indicates that this tendency exists for both adversaries.

Figure 6b Here

Effects of Cheap Cost-Effective Strategic Defense

The assumption behind Figure 6a/b showing a tangency of a utility contour with an opportunity set was that attack/offensive technology enjoys a cost advantage over defensive technology. This has surely been the case for the past 50 years at least, and most emphatically so with respect to air-space power. But now as an example of what a cheap missile defense might bring, consider the opposite case, where defensive systems operate at a cost advantage, and offensive systems are inherently more expensive. With Fig. 7 to illustrate, we use the same logic as before to construct budget lines B_1 and B_2. But compared to the earlier diagram the budget lines will be reversed. B_1 is now steep because Country 1 now has a low opportunity cost (measured in terms of F_2) of reducing damage to itself F_1. And now B_2 is flat, just the opposite of Fig. 6. When assuming that defense is cheap and offense is expensive it follows that $\beta_2/\beta_1 < \alpha_2/\alpha_1$. Fig 7 shows equilibrium at (point ω). Compared to Fig 6 both countries settle on less damage to the other as a strategic price for enjoying greater protection for themselves. If this reciprocal arms choice is compatible with no-first-strike stability as in Table I Row 3, then we have compatibility with MAS.[22]

Figure 7 Here

Offense-Defense Arms Races

To summarize: A full-blown analysis of equilibrium implied by Eqs. (1) and (2) we have not attempted. But we have demonstrated with various slices through this complex problem that strategic defenses or other more elaborate defense systems will not banish the arms race. Defenses complicate the simple arms race model, but the basic pattern of dynamic reciprocal external diseconomies persists. Exact patterns, moreover, depend crucially on the relative cost of offense vs. defense in conflict-of-forces technology, especially on "force neutralization ratios" whether they favor offense or defense, and on how this pattern varies with scale. Where costs shift in favor of defenses we expect a shift in the composition and level of strategic forces between adversaries, but not an end to the competitive process.

MISSILE DEFENSE AS A GLOBAL PUBLIC GOOD

Historically, proposed missile defenses deployments have failed our first three minimal tests for acceptability, technical capability, war avoidance stability, arms race stability. This is why they have always been rejected and never really reached the political test. But this is changing; technical and political changes of the past decade could make missile defense prospectively viable. However, a crucial new ingredient in this viability could be the opportunity that strategic defense be implemented as a global public good, collaboratively designed, financed, and provided by/among otherwise adversarial countries. I do not advocate this; I merely report it as an obvious possibility implied by the models and analysis of this paper.

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[22] John Warner points out that Fig. 7 being the reverse of Fig 6b, implies a contract curve outside of point ω, so that in Fig 7 for given budgets each side *over*-allocates to defense. Since duopoly arms outcomes are inefficient due to mutual diseconomies, they result in excess military budgets as well, and this inefficiency may offset the other.

First, the technical changes relate to the new possibilities for non-nuclear, space-based, boost-phase intercept of ballistic (and other type) missiles. Second, major political changes follow from the end of the Cold War. Rather than national (or alliance) oriented missile defense to advance individual interests, collaborative, international, universal missile defense to limit damage globally may pass all four tests in the near future.

With respect to the stability of war avoidance, historically, missile defense and Mutual Assured Survival have been postulated as a substitute for MAD deterrence. But a global missile defense could mean we can have both. Missile defense is essentially deterrence-destabilizing if a national or alliance weapons system, but if deployed as a global system it clearly has the potential to enhance deterrence stability. On a global basis we can have mutual survival *and* mutual deterrence. Of course there are many requirements for trust among countries which themselves could present stability challenges to be overcome, and protocols for shared command and control. I cannot resolve the numerous objections as to risks and obstacles to the required cooperation. The most an essay like this can do is point out the opportunity.

Cold War Compared to 21st Century

To repeat, strategic defense failed all four tests throughout the period 1950-1990. In the early years of this period ABM warheads were to be nuclear to compensate for accuracy deficits, and throughout the period target acquisition, engagement, and battle management technologies were never demonstrated. With respect to crisis stability, the examples of Table 1 and 2 are fairly representative of this period. ABM/BMD would actually have reduced the stability of no first use. As for arms race stability, the cost structure pictured in Figure 3a is representative, as studies from that period (e.g. Kent 1964 1989, Niskanen 1967, Bailey 1973) confirm. In those days an attacker could overwhelm missile defenses at far less cost than the defensive system itself just by increasing the scale of effort. But cost and technology are changing to favor defensive systems. Numerous developments of the past two decades point to this.

First, sufficient political changes just may have occurred to allow military collaboration. Cooperation, which was unthinkable 20 years ago, now may be attainable.[23] Second, new developments in boost phase target acquisition and intercept mean that missile defense could become not only technically feasible, especially once spaced-base anti-missile launch is perfected, but much cheaper relative to offense. Huge improvements have been made in target acquisition, engagement, and management. Smart weapons accuracy means that missile defense *without use of nuclear warheads* can become standard. Rather than shooting down a speeding bullet at its least vulnerable position (which is traveling 15,000 mph carrying multiple decoys and chaff) with another bullet, boost-phase intercept, will permit shoot-down when the attacker is most vulnerable. Because surveillance and boost phase intercept defeats attackers at their most vulnerable points, it should change the cost structure, so that against large-scale salvos it becomes *cheaper to defend than to attack* and the structure behind Fig. 3b applies [24] rather than Fig. 3a.

Note especially how these technical developments interact with the political if missile defense were implemented as a multinational public good. More specifically, boost-phase intercept should become still much cheaper with the *collaboration* of otherwise adversarial countries. The marginal costs of individual missile kills should decline dramatically, while counter measures aimed at raising the costs of defense could be restricted further limiting costs of defense. Presumably collaboration could be instituted step by step, beginning with shared real time information about missile launch status, to reciprocal territorial patrols, all the way to joint multinational force missile intercept command.

Third, collaboration would mean that global missile defense can be *financed as a public good* with costs shared among rivals/collaborators. Thus the costs of defense to any one party become only a

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[23] The demands on states' willingness to trust others when joining a collaborative missile defense are indeed notable, including a willingness to share sensitive secret information.

[24] New relatively cheap strategic defenses may indeed generate as a side benefit some protection against rogue states or nuclear terrorism, but on cost efficiency grounds I doubt that this could not be their primary goal. And strategic missile defense is no defense at all against surreptitious, individual, terrorist-like, weapons.

fraction of total costs, while the benefits are shared in a non-rival, non-exclusionary manner characteristic of public goods.

Fourth and most important, global missile defense can be configured so that it *enhances stability of deterrence* rather than undermines it like ABM would. In fact this advantage is inherent in global missile defense, just as instability is inherent in national missile defense. The reason: any multinational missile defense will be subject to resource constraints --- that is have only so many (N) interceptors. Therefore, there will have to be a limit to the number of missile killing intercepts it can effect --- N in number. Assume a global missile defense force would assign those N intercepts to the *first N* missile-away targets it acquires. If it does this, it will be *the initiator's attack force*, which is reduced most by missile defenses and not the retaliator's. And this will *diminish the advantage of striking first and possibly reverse it.* Moreover, to keep pace with any scale of build up by a potential first striker is cheaper than the costs of that offensive build up.

The conclusion ? Mutual Assured Survival (MAS) may become consistent with rather than competitive with MAD, *especially if it is based on strategic agreements between adversaries* and treated as an international public good. Treatment as a global public good implies something like a "Global Missile Launch Surveillance and Warning Authority," coupled with a "Multinational Missile Intercept Command," which would destroy attacking ballistic/cruise missiles once launched *irrespective of their origin*. To treat missile defense truly as a multi-country collective good, not a weapon for one nation's dominance or advantage, implies a massive change in political perspective. But internationalizing missile defense as a global public good may be the best or even only answer to the otherwise destabilizing properties of BMD.

Dynamic Perils and Limits of Comparative Static Analysis

Our models are incomplete; in addition they suffer from the defect that they are comparative static which gives rise to one particularly important problem. That is, even if the case for missile defense turned out to be clear and unimpeachable, a crucial danger could lie in the transition from deterrence based MAD strategy to defense-based MAS strategy--- *the danger that deterrence would fail before defense became effective*. (See Kent and DeValk, 1986; Radner, 1989) I have nothing to say about this peril, except that it becomes of special concern when defense is unilateral, non cooperative, and uncoordinated. If, to the contrary, missile defense were effected by multinational agreement, this dynamic risk would I believe be lessened.

CONCLUSION/PROPOSAL

This paper has been based on the supposition that international weapons competition may reemerge one of these years after a decade of subsidence. Given that premise we have asked once again whether MAD with its sword of Damocles is really the best to expect from the future. Or instead is MAS prospectively a viable alternative? In a Nash-Cournot world we have described how strategic defense could change the nature of strategic arms race equilibrium as well as maintaining the incentives to hold back attack in a crisis. The paper also suggests that the time may soon come to reevaluate MAS vs. MAD in the light of a new opportunity given to us by technical and political possibilities undreamed of at the time of the ABM Treaty. This is the opportunity for "public good" type collaboration between otherwise-adversaries to make Mutual Assured Survival a stable, affordable, complement to stable deterrence, and substitute for mutual obliteration. Is it time to replace the current reliance on MAD, not with deployment of nation-centered BMD, but rather with its renunciation? Is the time to replace MAD with global-oriented defense approaching? If and when the technical and economic parameters indicate an affirmative answer, then comes consideration of a pact among the major powers, universally to limit potential damage by using defensive systems including missile defenses not as a measure of partisan domination but for the global public benefit that it would create? The political analysis of this possibility goes far beyond this paper.

Meeting Gorbachev in Iceland in 1985, President Ronald Reagan spontaneously offered to share missile defense technology with the USSR, a move, which it is said, alarmed his advisors. Twenty years later, in view of political, technical, and economic developments since then, the time to follow through on his proposal may soon arrive. Rather than national (or alliance) oriented BMD to advance individual national interests, collaborative, international, universal missile defense to limit damage globally can pass the tests which earlier versions failed. Our technical and political R&D should focus on this path to implement Mutual Assured Survival simultaneously with Mutual Assured Destruction. The current debates over missile defense should not lead to decisions, which have overlooked this Reaganesque opportunity.

Appendix

Is BMD an Offensive or Defensive Weapon?

The analysis in the text assumes offensive and defensive weapon systems combat or duel with each other. It is in this context that relative cost effectiveness drives the viability of MAD vs. MAS. On which side of this combat-duel do we place missile defense? The short answer is it can be either/both an offensive and a defensive weapon depending on its deployment and its functioning in the various scenarios. It will have different effects and generate different incentives depending on whether it protects cities only, or own strategic offensive forces or both cities and forces. These will influence its first vs. second-strike consequences and incentives. The crucial difference depends on how missile defense (or any strategic defense) functions *in support of a first strike* compared to its use as a *complement to a retaliatory ability*.

A missile defense may be technically most effective at deflecting an enemy's retaliation that has responded to our own first strike. Such a missile defense is an *offensive weapon*, as it improves own first strike capacity by making us safer from punishment. In fact such a capability may provide one with an incentive to strike first (with impunity), and therefore undercut of deterrent stability. On the other hand, a missile defense could conceivably have a comparative advantage in protecting "us" against an enemy first strike, and conceivably not do much against an enemy's retaliation responding to "our" first strike. A defense system like this would be a *defensive damage-limiting weapon*, and would provide an incentive to refrain from attack (since it works better to save us from unprovoked destruction, than to support our own provocations).

Which of these alternatives better describes BMD depends on its design, capabilities, and the details of its deployments and utilization. Especially crucial must be the design response-effectiveness of missile intercept systems in combination with all other defenses *to increasing levels of attack*. Once again we must deal with the scale issue: how a missile defense handles *increasing scale of attack* is crucial. The following examples to follow help explain what this means and why it is important.

Example: Hard Point Defense. Suppose first that BMD is used as a local "point defense" defending land-based ICBM's, air bases, and submarine docks. A system used solely in this way is like hardening ICBM silos. BMD of this nature raises the size of an attack force needed to disarm a defender. One can substitute this kind of BMD for offensive forces without lowering ones 2^{nd} strike retaliatory abilities. For the sake of argument suppose such use of local point defense, assuming no simultaneous defense of cities whatsoever. Such a point defense enhances-maintains MAD, preserving a secure second-strike retaliatory capability. Note also that a substitution of point-BMD for our missiles would reduce our first strike counter city ability, *and* our first strike counter force ability. That is having fewer missiles (because we substituted point BMD for some of them) we are less effective in destroying enemy missiles in a first strike, and also less effective in attacking enemy cities out of the blue. If all adversaries install this kind of "point defense" only, and leave their cities exposed, and reduce the number of their (now more secure survivable) offensive forces, *then MAD is mutually reinforced*. Both sides would now (with point-missile-defense) have a lowered ability to destroy the other's cities with a surprise attack, and would have an unchanged retaliatory ability. Thus, hard point defense may reduce damage from surprise attack (if both MAD oriented sides reduce their missile inventories when they deploy point defense BMD) without altering 2^{nd} strike retaliatory MAD commitments. Because of the first effect one should call point-missile-defense a defensive weapon, but because of the second could call it a deterrent weapon.

Example: Cities Only Defense. Alternatively consider next a BMD which protects only cities, and provides no protection whatsoever for ICBMs or SLBMs etc. or prospective space-based weaponry. This also is a useful assumption for decomposing actual BMD into its component effects, not because actual BMD systems would have this property. Still, a system that protected only cities would assumedly protect them both from a surprise first strike and from an enemy's counter-value retaliation.

In this case the *relative performance* of BMD in defending against large numbers of surprise incoming missiles vs. smaller numbers of retaliating incoming missiles is crucial. Just to give a simplified example, assume that X enemy missiles impacting on American cities would cause a population loss of 50%, needless to emphasize a devastating loss. Suppose also that missile defense itself is invulnerable to attack and can intercept 150% of X incoming missiles with 100% assurance, but no more. Now for the sake of argument imagine that an enemy had 2X missiles as potential attackers, and that with a first counter force strike we could eliminate X of them. Then our first strike would reduce the retaliatory damage to our cities to zero (X destroyed by our counter force strike, and X defeated by our missile defense). But with the same set of our forces, a surprise counter city attack from the enemy would force us to absorb 0.5X impacts (as postulated we can intercept only 1.5X of the 2X enemy attackers with our city-only defenses); and these .5X impacts would terribly wound our society with say a 35% loss of population and capital assets.

A cities-only missile defense of the character just described has damage-limiting benefits but at the same time reduces/reverses the incentives to refrain from attack. And if both sides have such a system then both suffer from this inversion of incentives. Such defense may in a twisted sense improve "Survival," but it is not "Mutual" and most certainly not "Assured." Missile defense of this nature, failing the "stability of no-initiation" incentive, is inconsistent with both MAD and MAS. A missile defense such as this is unstable.

If a cities-only defense had a different effectiveness/performance pattern, one's evaluation of it would be different. For this example, imagine defenses allowed the first X/2 incoming missiles[25] to slip through while it was 100% effective against all incoming attackers after the first X/2. Then installation of this defense would eliminate all advantage of attacking first, and therefore reinforce MAD. It would reduce maximum war damages to both sides and make the loss from striking first identical with the loss from defending cities against an enemy first strike, thereby passing a stability of no first use test

Example: Combined City Defense/Forces Defense. It is unlikely that a deployed defense would consist either exclusively of protection for cities or exclusively of protection for forces. It probably will have combined elements of both. Most systems involve acquiring and destroying launched missiles at various phases of their trajectories *irrespective of their destinations*, whether cities or forces. Thus realistic systems will share features of both "pure" cases described above. It may increase or decrease MAD, or it may increase or decrease MAS. Just as an example, assume defensive systems were employed by both adversaries. Suppose on each side defenses destroyed β% of the first Y missiles (RV's, pounds of payload, etc.) to intrude *irrespective of their targets* (which might be impossible to calculate anyway). Then we could analyze the effect of missile defense deployments in two phases. First consider its effect on the security of weapons. Because home missile defenses would save home missiles from destruction it *increases* their deterrent value as retaliatory weapons. Because foreign defenses would dilute our surviving retaliatory weapons' counter-value retribution, it *decreases* their contribution to deterrence. Second consider the city-protection effect of our missile defense. Because of our defenses, damage to our country's population and other assets should decline, but because of foreign defense, the adversary may have more surviving payload for retaliation and therefore should increase our damages (and symmetrically for the adversary).

[25] Again, I use the word "missile" to indicate reentry vehicles, payload, etc. indiscriminately throughout this paper.

These examples illustrate the ambiguity in missile defense. Does a technically effective, cheaper, more efficient missile defense system aid the cause of MAD or MAS? Because of differential effects defenses may have on damages from initiating vs. retaliating, it may do one or the other, both or neither, depending on the specific parameters of missile/anti-missile effectiveness, depending on the scenario, and the intentions of its owner. Examples such as these clearly illustrate how the missile defense debate is really about the larger question of choice of nuclear strategy. There is not one single missile defense but many. Given an effective technology, the same system may have very different consequences for offense-defense force duels under different scenarios. This means that to think about missile defense exclusively or primarily as a defensive damage limiting weapons system is mistaken. Its functions in deterrence and defense are complex and intertwined. Moreover deterrence and defense are not opposites, nor are they mutually exclusive. Just because a country values and deploys missile defense for its damage limiting abilities, does not mean such deployment undermines deterrence.

Acknowledgments

Earlier versions of this paper were read at the Western Econ. Assn. Meetings San Francisco 2001, American Economic. Association. Meetings Atlanta 2002; Aoyama Gakuin University, Research Office of the Cabinet Secretary Japanese Diet, UCLA, and UC-Irvine. I thank Ray Dacey, Jack Hirshleifer, Toshihiro Ihori, Mike Intriligator, Patrick Morgan, Hiroshi Ohta, David Rothman, Todd Sandler, Bernard Springer, and Earl Thompson for comments.

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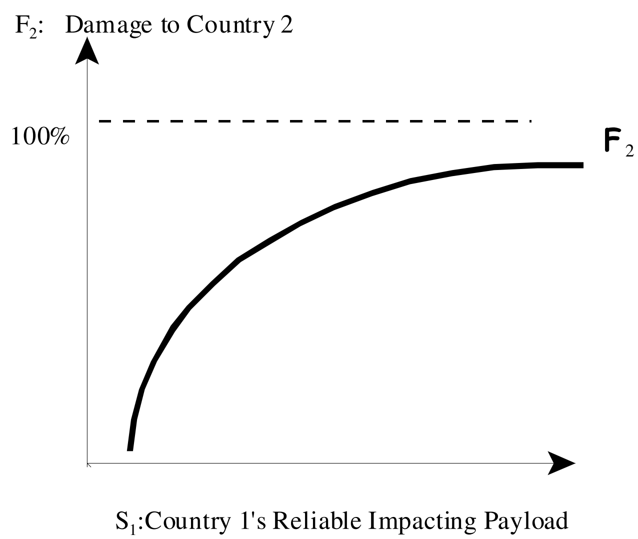
Table I: Deterrent Stability
Equally Matched Symmetric Countries

	Loss to Side That Initiates	Loss to Side That Retaliates
1. Deterrent Stability w/o Missile Defense: Characteristic 1965-Present	20%	60%
2. A Missile Defense That Destroys Deterrent Stability: Characteristic 1965-Present	1%	41%
3. A Missile Defense That Enhances Deterrent Stability: Possible BMD in the Future	20%	5%

Table II. Examples of Deterrent Stability with Asymmetric Countries and Forces

	Loss to Stronger Side	Loss to Weaker Side
I. Deterrent Stability Without Missile Defense		
Stronger Country Initiates/Weaker Retaliates	5%	40%
Weaker Country Initiates/Stronger Retaliates	20%	30%
II. Unilateral Missile Defense Destroys Deterrent Stability		
Stronger Country Initiates/Weaker Retaliates	1%	40%
Weaker Country Initiates/Stronger Retaliates	5%	30%

Figure 1



F_2: Damage to Country 2
100%
F_2
S_1:Country 1's Reliable Impacting Payload

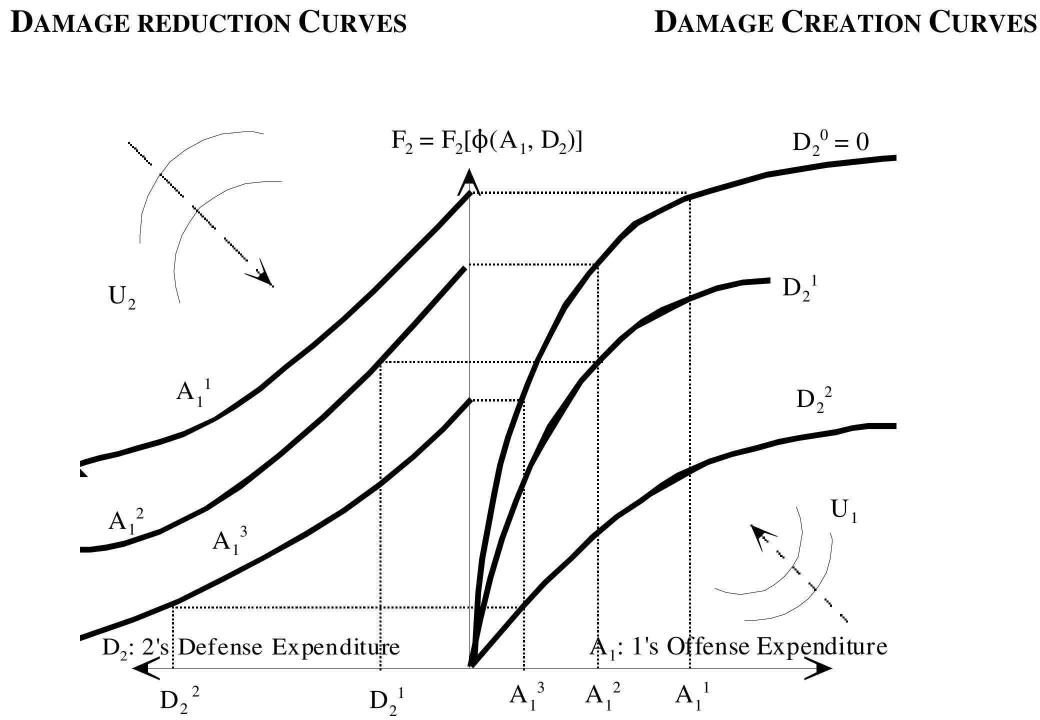


Figure 2: Offense-Defense Competition

Figure 3a
Offense Defense Force Neutralization Ratios
Protection is Very Expensive at Middle Damage Levels
Relative Costs Favor Offense

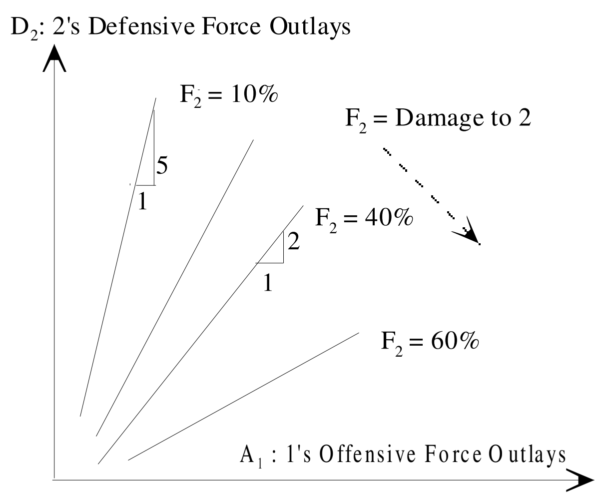


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Figure 3b
Offense Defense Force Neutralization Ratios
Protection is Expensive Only at Very Low Damage Levels
Relative Costs Favor Defense

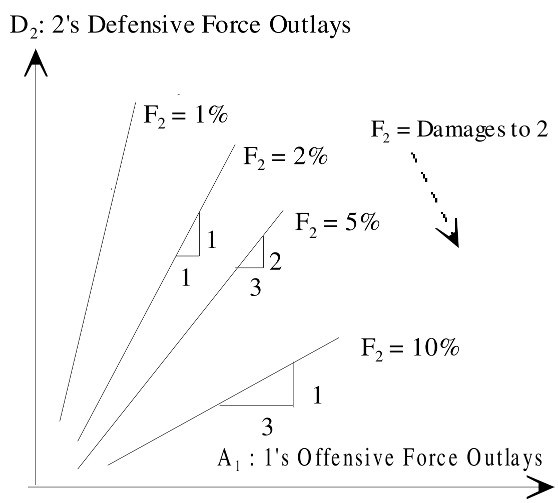


Figure 4
Nash Equilibrium Depends on
Relative Cost Effectiveness of Defense

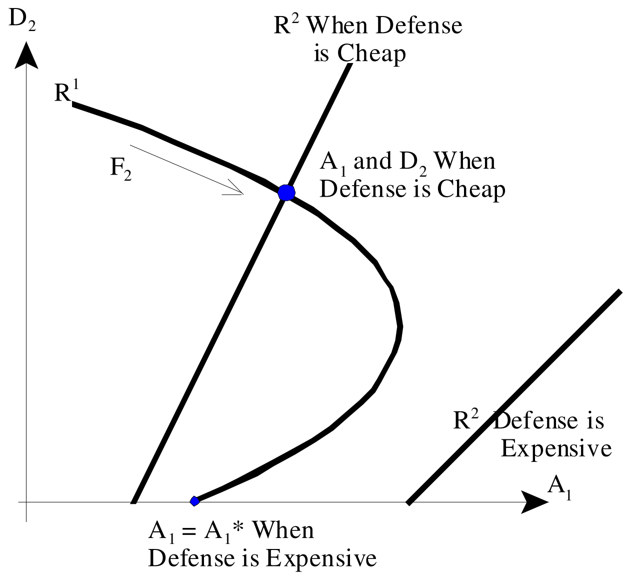
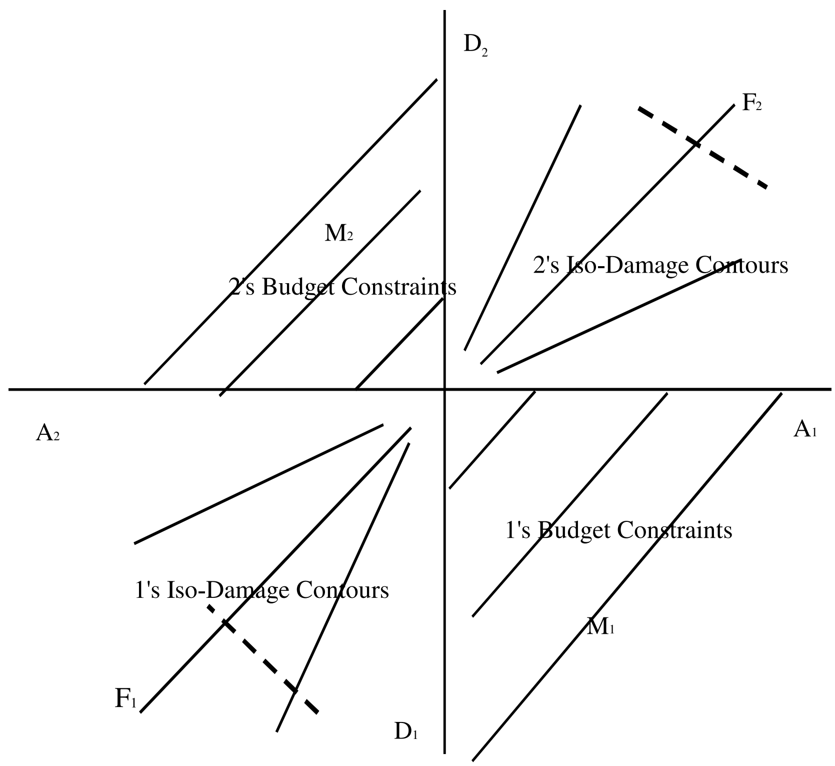


Figure 5
Dual Deterrence-Defense Budgets
And War Outcomes



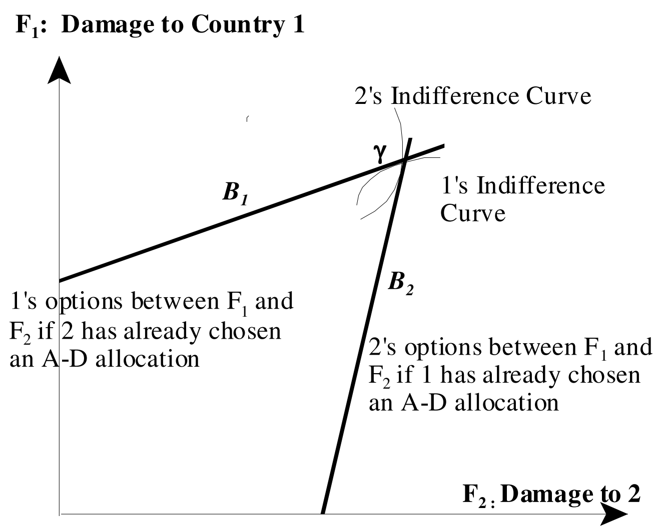


Figure 6a
Nash Equilibrium Choices of Attack-Defense Mix When Total Strategic Budgets are Given and When Defense is Very Expensive

Figure 6b
Reaction Curves and Nash Equilibrium Choices
When Defense is Very Expensive

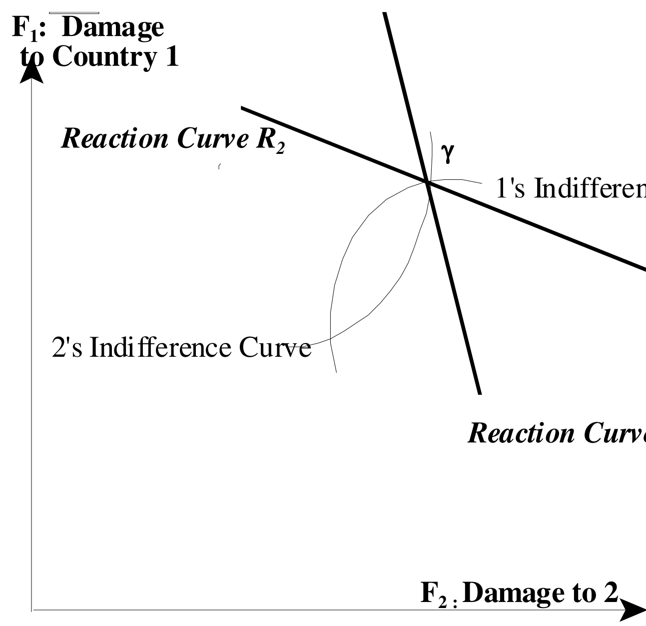


Figure 7
Nash Equilibrium Choices of Attack-Defense Mix
When Total Strategic Budgets are Given and
When Defense is Very Cost Effective