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THE RACE IN ARMS: IT'S MATHEMATICAL COMMONSENSE

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The Race in Arms: its Mathematical Commonsense*

by

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A B S T R A C T

The paper sets up a system of coupled differential equations to exhibit military interactions. The twin military objectives of domination and deterrence emerge as cases of "strong" and "weak" interaction. It follows from this argument that the instability of the arms race is a consequence of "strong" interaction, irrespective of whether offensive or defensive (e.g, "Star Wars") strategies are pursued. Finally, the argument is enjoyed by only one side may create greater manoeuvrability for stabilizing a regional arms race.

R E S U M E N

Este trabajo modela las interacciones militares con un par de ecuaciones diferenciales simultáneas. Los objetivos militares gemelos de dominación y discusión aparecen como casos de interaccion "fuerte" y "débil". Por ello concluímos que la inestabilidad de la carrera armamentista resulta de la presencia de interacciones fuertes, independientemente del hecho que las estrategias sean ofensivas o defensivas (por ejemplo el caso de la "Guerra de las Galaxias"). Finalmente, extendemos este argumento al caso de carreras armamentistas locales para mostrar como el acceso a la discusión nuclear por un sólo de los contrincantes puede aumentar el margen de maniobra que se necesita para estabilizar una carrera armamentista regional.

We all know the intuitive logic behind an arms race. whenever two adversaries try to dominate one another in terms of military strength, they end up chasing one another in armament build-up. The resulting arms race -usually based on the false doctrine that "negotiations are possible only from a position of military strength"- is unstable; because neither side is willing to compromise on the basic motive of attaining superiority in its military position. This is the simplest, and yet, the most fundamental reason behind any arms race, no matter whether it is between two superpowers or two regional powers.

To capture mathematically such an unstable race in arms, consider two adversaries, whose respective arms stocks are (unidimensionally) measured by x and y respectively. The desired armament stock of country X is x^* and that of country Y is y^*. However, given the motive of military domination, the desired stock by either country must exceed that of its adversary. Formally, this can be represented as,

$$x^* = a.\, y \quad , \quad a > 1 \quad \ldots\ldots\ldots\ldots\ (1)$$

and,

$$y^* = b.\, x \quad , \quad b > 1 \quad \ldots\ldots\ldots\ldots\ (2).$$

The current rate of armament build up by either country depends on its perceived gap between its desired and actual stock i.e.,

$$\frac{dx}{dt} \equiv \dot{x} = m\ (x^* - x)\ ,\ m > o\ \ldots\ldots\ (3)$$

and, $$\frac{dy}{dt} \equiv \dot{y} = n\ (y^* - y)\ ,\ n > o\ \ldots\ldots\ (4)$$

The parameters m and n are the "speeds of adjustment" of the actual stock to its desired level in the respective countires. Thus, if country X tries to cover its perceived gap in arms in say, 4 years then, $m = 1/4$ years.

Inserting (1) and (2) in (3) and (4) respectively, we have a simple system of linear, <u>coupled</u> differential equattions in the following form:1/

$$\begin{bmatrix} \dot{x} \\ \dot{y} \end{bmatrix} = \begin{bmatrix} -m & ma \\ nb & -n \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} \ldots\ldots\ldots\ (5)$$

It is clear that the eigenvalues of its characteristic equation,

$$\lambda^2 + \lambda\ (m + n) + m\ n\ (1 - ab) = o$$

have negative, real parts if and only if

$$a\ b < 1\ \ldots\ldots\ldots\ldots\ (6)$$

Thus, the arms race depicted by (5) can stablize at its stationary value at the origin (o,o) only if (6) is satisfied. However, this condition (6) is contradicted by the postulate of military domination motive, namely $a > 1$ and, $b > 1$ assumed in (1) and (2) respectively. Consequently, we have confirmed our intuitive understanding that an arms race can not be stable when both sides try to dominate militarily.

For expositonal convenience, the preceding mathematics was kept to its bare essentials. The analysis could be complicated by "shifting" the origin and allowing the stationary value of (5) to be obtained at positive values of x and y. This would mean incomplete disarmament as a possible position of equilibrium, unlike (5) which specifies complete disarmament as the only possible equilibrium position.[2/] Similarly, the speeds of adjustment, m and n need not be constant. For instance, m or n could be zero, whenever there is no perceived gap e.g., $(x^* - x) \leq o$ entails $m = o$. Such an assumption would rule out the assumption of "running down" of arms stock through inadequate replacement, but would not qualitatively change the preceding analysis.[3/] Higher or lower values of the speeds of adjustment would only set the arms race in faster or slower motion without affecting its stability property given in (6).[4/] It would also be trivial to 'non-linearize' the domination motive by replacing (1) e.g,

$$x^* = f(y), \text{ where } f(y) > y \text{ and } f' > o \quad .. \text{ (1a)}$$

In this non-linear case, the local stability condition would be the same as in (6), except that the parameter 'a' in (6) has to be interpreted then as the value of the derivative of (1a) evaluated at the stationary or equilibrium position.

More interestingly, even this simple model emphasises the crucial influence of military intelligence on the arms race. For instance, the military intelligence of country X may be systematically overestimating (deliberately or otherwise) the armament stock of country Y by some factor k, where $k > 1$. The adversary's estimated stock according to military intelligence is then, $\hat{y} = ky, k > 1$.

In so far as the desired stock of country X is based on such overestimated strength of country Y, we have, instead of (1),

$$x^* = a\hat{y} = a\,k\,y \quad , a > 1 \text{ and } k > 1 \ldots. \quad (1b)$$

As (1b) suggests, deliberate disinformation leading to systematic overestimation of the adversary's military strength is just another way of hiding the more blatant motive to dominate. Not surprisingly, this can only destabilize an arms race further.[5/]

If domination is the motive to gain military supremacy, deterrence is its obverse. It consists of the ability to deter the adversary from attaining a position of military supremacy. This doctrine of deterrence assumed exceptional significance in a climate of thermo-nuclear stalemate in the post-second world war era. Possession of nuclear weapon meant that either superpower now had the ability to inflict overwhelming and indiscriminate damage to its adversary (civilian as well as military) even in a retaliatory second strike. This level of damage is considered so large as to be unacceptable by the potential first-striker. And, it results in the ability to deter the adversary from gaining a position decisive military supremacy to launch any first strike attack.

Suppose we represent such an "adequately" deterrent position by a certain level of military strength, which is $\bar{x}$ country X.[6/] So long as this adequately deterrent position does not depend on the adversary's armed strength, instead of (1), we have,

$$x^* = \bar{x}, \text{ an arbitrary positive constant}\ldots\ldots (1c).$$

According to (1c), country X desires an independent deterrent policy, not in the least influenced by its adversary's military strength. Therefore, it cannot be drawn into the arms race. It follows that the arms race is necessarily stable at the point where, country X has built up its adequate, independent deterrence power ($\bar{x}$). This can be formally checked by replacing (1) by (1c) and examining the stability property of the resulting differential equation system described by (1c), (2), (3) and (4).

In formal terms, replacement of equation (1) by (1c), uncouples the system of differential equations. This is the logical extreme case, where country X refuses to interact militarily with country Y altogether. From this point of view, domination can be considered as a case of strong military interaction, represented by 'high' values of the parameters 'a' and 'b', each exceeding unity in equations (1) and (2). Obversely, an independent deterrent strategy lies at the other extreme with no military interaction. Inbetween these two polar cases, there lies a whole spectrum of weak military interaction, where at least one side responds relatively moderately to the military build up by its adversary. This could be represented by parameter 'a' or 'b' in equation (1) or (2) taking a value less than unity. From earlier stability condition (6), it would be immediately obvious that such moderate response by at least one side improves the possibility of stabilizing the arms race.[7/] But therein also lies the tragedy of an arms race: even if country X is very moderate in its response i.e, the parameter 'a' takes a value well below unity, a sufficiently strong domination motive by country Y, represented by the value of parameter 'b' far exceeding unity, can still destabilize the arms race by violating condition (6). In other words, it would take both sides to stabilize an arms race; but it takes one side to destabilize it, except when one country

<u>follows an independent strategy of adequate deterrence</u> (as in (1c)).

Unfortunately, the persuit of any <u>independent</u> policy of adequate deterrence is jeopardised by its own logic. Effective deterrence requires the country following such a policy to maintain an unacceptably high level of destructive power vis-a-vis the adversary. Consequently, any improvement even in the defense capability of the adversary would reduce his perceived level of threat. In turn this would undermine the deterrent power. It becomes pointless in such a situation to distinguish between "offensive" and "defensive" weapon systems in propelling an arms race. Either type of weapon system may fuel the arms race as increased "defense" capability of one side induces the other side to increase its expenditure on "offensive" weapons in an attempt to maintain its adequate power of deterrence. <u>This blurring of the distinction between offensive and defensive weapons is inherent in the logic of deterrence</u> insofar as reliance has to be placed on offensive weapons to threaten the adversary for achieving defense objectives.[8/]

Consider the case of country X wanting to maintain an adequate deterrent position with <u>offensive</u> armed strength. Using subscript 'o' to denote of offensive strength, we can rewrite (1c) as,

$$\bar{X} = \bar{X}_o$$

However, its deterrent strength may be continously undermined from $\bar{x}_o$ due to defensive arms possessed by its adversary Y. Thus, the desired stock of offensive arms of country X i.e, x_o^* must be such as to maintain its deterrent strength at $\bar{x}_o$ despite the defense capability of its adversary Y. Using subscript 'd' to denote defensive strength, a simple (and analytically most easily tractable) formal way of representing this is,

$$\bar{x}_o = x_o^* - F(y_d) \quad , \quad F' > o$$

or, $$x_o^* = \bar{x}_o + F(y_d) \qquad F' > o \quad \text{..........} \quad (1d)$$

where, Y_d represents the stock of defensive arms of country X and the function 'F' represents some specific way in which defense capability of Y undermines the deterrent strength of X. It is obvious that (1d) has a similar mathematical form encountered earlier in (1a), except for the constant term $\bar{x}_o$ representing the deterrent strength of X vis-a-vis Y. Therefore, one would expect the earlier analysis to hold: the arms race would become unstable
if the military interaction is strong between offensive weapon acquired by X (i.e x_o) and the defensive weapon acquired by its adversary Y (i.e, y_d).

To elaborate the analysis, assume country X concentrates entirely on offensive weapons in pursuit of its deterrence strategy whereas, country Y concentrates entirely on defensive weapons to reduce its perceived level of military threat. Thus, country Y would desire its stock of defensive weapons to be such as to reduce the military threat to some arbitrarily low constant level A, where, $\bar{x}_o > A > o$. i.e, 9/

$$A = x_o - F(y_d^*) \quad , \quad \bar{x}_o > A > o$$

or, $$y_d^* = F^{-1}(A + x_o) = G(x_o) \quad , \quad G' > o \quad .... (1e).$$

where, $F^{-1} \equiv G$

Inserting (1d) and (1e) in relations (3) and (4), the local stability of the coupled system of differential equations can be seen to be guided by the condition,

$$F' \; G' < 1 \quad ....(7)$$

where, the derivatives F' and G' are evaluated at their equilibrium values (provided such an equilibrium exists). We have therefore arrived at the expected result in (7) in accordance with (6). Even if one country, Y in this case, maintains a dominantly defensive posture in terms of strengthening only its defense system, the arms race can still become unstable, if interaction is strong i.e, condition (7) is violated. 10/ The basic reason for this is worth recalling: the doctrine of deterrence creates the "paradox of security" where, a country's security is enhanced only by undermining that of its adversary. Therefore, if the initial situation is already one of deterrence based on mutually assured destruction (MAD), it makes little sense to draw a distinction between "offensive" and "defensive" weapon systems irrespective of the physical characteristics of those weapons, at least in sofar as the continuation of the arms race is concerned. Indeed, increased defense capability at the margin (measured by the derivative F' in (1d)) would further destabilize an arms race by upsetting the existing balance of deterrence among the two super-powers.[11/] In other words, the intensity of mililary interaction, irrespective of whether the response is in terms of "offensive" or "defensive" weapon systems, continues to be the crucial determinant of the arms race, when deterrence defines the initial condition.

The importance of the above proposition can be more fully appreciated once we divert our attention from super-power to regional arms races. Suppose country X not only has conventional weapons but also enjoys nuclear deterrence vis-a-vis its adversary Y. However, this happens to be one-sided nuclear deterrence, because country Y possesses no nucleat capability; its only option is to try to maintain superiority in terms of conventional weapons as its policy of deterrence.[12/] The nature of this one-sided nuclear deterrence enjoyed by country X is best established through its declared policy of renunciation of first nuclear strike in all cases. Under these circumstances it is worth while to investigate whether country X, assured by its one-sided nuclear deterrence power, is in a position to exert a stabilizing influence on the regional arms race by reducing the degree of intensity in military interaction. In other words, we seek the analytical conditions under which nuclear deterrence enjoyed by only one side may have some possibility of bringing the regional arms race to a halt.

Denoting by subscript 'c' and by subscript 'n', conventional and nuclear weapons respectively, the problem can be set out more formally.

Let the desired stock of conventional weapon of country X (i.e, x_c^*) increase as the adversary's conventional stock (Y_c) increases through usual military interaction described in (1) to (1d). However, this desired stock x_c^* decreases as country X itself possesses more nuclear weapons (x_n), partly because it requires less of conventional weapon to deter the enemy from attacking (i.e, the strategic motive of deterrence) and, also partly because, constraint on the overall defense budget would reduce allocation for conventional weapon programme due to a larger nuclear weapon development programme. Thus, the desired stock of conventional arms for country X is represented by;

$$x_c^* = a\, y_c - h\, x_n \,, \quad a > o, \; h > o \quad \ldots\ldots\ldots\ldots \;(8)$$

where, x_n = stock of nucelar weapons possessed by country X.

Obversely, the desired stock of conventional weapons of country Y (which, by assumption possesses no nuclear weapons) is given as,

$$y_c^* = b\, x_c + p\, x_n \;,\; b > 1 \;,\; p > o \;\ldots\ldots\ldots \quad (9)$$

Note that country Y would normally desire to maintain superiority in conventional arms (i.e, $b > 1$), as its only option to a strategy of deterrence agains the adversary. In addition, it may desire to increase further its <u>conventional</u> strength if the adversary X increases its nuclear strength (i.e, $p > o$ in (9)).

We depict the <u>one-sided nuclear deterrence strategy</u> of country X by assuming that it increases its nuclear strength whenever it lags behind its adversary in conventional weapons. In the simplest form, this is represented by,

$$\dot{x}_n = g\,(y_c - x_c) \;,\; g > o \;\ldots\ldots\ldots\ldots\ldots \quad (10)$$

where, g is the speed of adjustment for nuclear weapons.

Inserting (8) and (9) in (3) and (4) respectively and using (10), we have the following system of differential equations depicting the <u>regional arms race with only one side possessing nuclear weapons</u>:

$$\begin{bmatrix} \dot{x}_c \\ \dot{x}_n \\ \dot{y}_c \end{bmatrix} = \begin{bmatrix} -m & -mh & +ma \\ -g & o & +g \\ nb & np & -n \end{bmatrix} \begin{bmatrix} x_c \\ x_n \\ y_c \end{bmatrix} \quad \ldots\ldots \quad (11)$$

Like our previous equation system (5), (11) is chosen (for simplification) to be homogeneous. This means (11) also has an equilibrium or stationary solution at the origin (o,o,o) representing the configuration of total disarmament.[13/]

The characteristic equation of (11) is given by,

$$\lambda^3 + (m + n)\ \lambda^2 + \left[m\,n\,(1 - ab) - g\,(np + mh)\right] \lambda + mng(ap+bh-p-h) = o \quad \ldots (12)$$

It can be checked that all the eigenvalues of equation (12) would have negative real parts so that the origin would represent a stable equilibrium (stationary) position if,[14/]

<u>Condition A</u>: $(m + n) > o$, always satisfied.

<u>Condition B</u>: $mn\,(1 - ab) > g\,(np + mh)$

<u>Condition C</u>: $(ap + bh) > (p + h)$

and, <u>Condition D</u>: $mn\,(m + n)\,(1 - ab) > g\left[mn(ap+bh) - (m^2h + n^2p)\right]$

Note that conditions B and C together imply that military interaction in terms of conventional weapons must be weak on the one hand (i.e, $ab < 1$ from condition B); but on the other, one side must be guided by the motive to dominate in terms of conventional weapons (i.e, a <u>or</u> b must necessarily <u>exceed</u> unity to satisfy condition C). This is ensured by (9) where, $b > 1$ and condition (B) can only be satisfied if $a < 1$ to make $1 > ab$ possible.

Conditions (A) to (D) also establish that the speeds of adjustment (parameters m, n and g) do matter in affecting the stability property in more complex situations of the arms race, in contrast to the simpler stability condition (6) or (7). However, we can considerably simplify the above conditions (A) to (D) by assuming that the speeds of adjustment are roughly of the same order i.e,

$$m = n = g \text{ (by assumption)} \qquad (13)$$

In this <u>special case</u> of equal speeds of adjustment given by (13), the above conditions (B) and (D) simplify respectively to,

Condition (B.1): $(1 - ab) > (p + h)$

and, Condition (D.1): $(1 - ab) > (ap + bh) + (p + h)$

It is evident that, (D.1) entails (B.1) so that, we are left only with Conditions C and (D.1) to be satisfied for the stability of the arms race in the special case given by (13).

Some straight forward numerical examples (e.g. a = 0·2, b = 2·0, p = 0·1 and h = 0·1) show that Conditions C and (D.1) can indeed be simultaneously satisfied. Thus, there is <u>some possibility of such a regional arms race to stabilize when it operates under one-sided nuclear deterrence</u>. <u>Not</u> to insist on superiority or even parity in terms of conventional weapons (i.e, $a < 1$ while $b > 1$) so long as a country enjoys one-sided nuclear deterrence is perhaps the most important necessary, but not sufficient condition for this. In general, weak military interaction, implying all the cross product terms ab, ap and bh sufficiently small to satisfy (D.1), becomes a realizable possibility for the country enjoying the protection of one-sided nuclear deterrence. However to realize such potentialities for stabilizing the regional arms race, it is essential to have the wisdom to recognize that moderation and not over-reaction can be an expression of genuine strength that is guaranteed by one-sided nuclear deterrence. It is tragic when the politics of populism prevents strength from expressing itself through moderation in military matters.

Footnotes

1/ The resulting system of equations (5) can be seen to be formally similar to the celebrated equations of Richardson (1960) in so far as, Richardson's "defense" terms correspond to our parameters '*ma*' and '*mb*' here, while his "fatigue" term has the value of $-m$ and $-n$ here. Our interpretation is different from that of Richardson because, we are primarily interested in formally capturing the motive of military domination.

2/ This would result in a system of non-homogeneous equations, where the constant non-homogeneous terms was described as the "grievance" term by Richardson (1960).

3/ It would be evident from an analysis of the phase diagram of (5); see Bhaduri (1982). However, a very high rate of obsolescence of the weapon systems --an expression of the technological aspect of the arms race--justifies the notion of negative rate of arms build-up i.e; net disinvestment in arms. It may be recalled that such negative net investment (at zero gross investment) plays a crucial part in the "upturn" of several endogenous cycle models.

4/ I,e, so long as the speeds of adjustment m and n are not functions of x and y to avoid serious non-linearities.

5/ Stockholm International Peace Research Institute in its *Yearbooks* repeatedly pointed out how the CIA has been known to have a systematic upward bias in estimating Soviet military expenditure e.g, see SIPRI Yearbook (1981) pp. 8-12. Pardos (1982) provides some detailed account on this point The mathematical condition for stability in presence of such overestimation would be, $abk<1$ which is obviously more stringent if $k>1$.

6/ $\bar{x}$ may now to be measured (imperfectly) in the number of nuclear warheads. See, McGuire (1977) for a summary of this measurement problem.

7/ I.e, it is a necessary but not sufficient condition.

8/ This is the "paradox of security" ________ the national security is enhanced only by undermining that of the other!

9/ Note the function 'F' may not be estimated to be the same by countries X and Y in general in (1d) and (1e) respectively.

10/ If country Y has *only* defensive weapons, it cannot by definition launch any attack (e.g, digging tunnels against nuclear fall-out). In such a case, a strategy of deterrence based on second strike becomes unjustifiable for country X. We rule out this extreme case in the discussion where country Y has no offensive strength whatsoever.

11/ Its relevance for Strategic Defense Initiative (popularly) known as "Star Wars") should be evident. Note in our mathematical representation, a higher value of the derivative F', measuring effectiveness of defense system at the margin, would make the stability condition (7) more stringent.

12/ Israel vis-a-vis its adversaries in the Arab world or India vis-a-vis Pakistan may well be real-life examples of such one-sided nuclear deterrence.

13/ See earlier footnote (2) and the related discussion.

14/ Following conditions (A) to (D) follow from the application of Hurwitz's well-known theorem. Accodring to it (simplified for our present purpose), the characteristic equation,

$$\lambda^2 + a_1 \lambda + a_2 = o$$

have real parts of the roots negative if, $a_1 > o$ and $a_2 > o$ (see equation (5) and condition (6)). For the third-order polynomial (as in (12)),

$$\lambda^3 + a_1 \lambda^2 + a_2 \lambda + a_3 = o$$

the real parts of the roots are negative if, $a_1 > o$ (Condition A), $a_2 > o$ (Condition B), $a_3 > o$ (Condition C) and, $a_1 a_2 - a_3 > o$ (Condition D).

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