The Macrotechnology of Conflict

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Decision makers must balance between two classes of economic activities: production and confl\ict. Analogous to the familiar technology of production and exchange is the technology of conflict and struggle, applicable not only to military combat but also in domains such as redistributive politics, strikes and lockouts, litigation, and crime. The conflict success function (CSF) takes as inputs the fighting efforts on the two sides and generates as outputs the respective degrees of success achieved. A crucial determinant of the outcome is the decisiveness parameter, which scales the degree to which force preponderance translates into differential success. Because success feeds on success, in the long run a hegemonic outcome is likely unless the decisiveness parameter is relatively low. The CSF can be adjusted to distinguish between offense and defense, allow for geography and organization, or even display how intangible considerations such as truth or morality can promote success.

There are two main ways of making a living: by production or by conflict. Consequently, two distinct technologies must be distinguished: the familiar *technology of production and exchange* on one hand, and the *technology of conflict and struggle* on the other. In optimally balancing between these two technologies, each decision maker will be influenced by (among other considerations) the pattern of resource endowments, time preferences and risk preferences, the perceived capacities and intentions of opposed parties, the number and strength of allies, and so on. And the equilibrium outcome, which might be a time path of periods of peace and periods of war among the various contenders, will be affected by all of these factors together with unanticipated and random events.

This article does not address the full problem of general equilibrium in such a broad context. Instead, I focus on only one piece of the problem, the aspect that will perhaps be the most novel for economists: to wit, the *technology* of the conflict process. In particular, it will be asked, How do the commitments of forces on each side enter into determining the outcome of struggle? For example, does victory always go to the larger battalions, and if not, why not?

The interplay between the technology of conflict and the technology of production and exchange underlies all the domains of human contention. A politician might aim to win voters' support by faithful service and wise decisions or else by denigrating and

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disabling opponents. An individual vulnerable to litigation might act to leave no just cause for being sued, or alternatively might invest in defense lawyers skilled at delay and obfuscation. A labor union might help its members earn high pay by encouraging worker sobriety and productivity, or else by threatening to disrupt the employer's production schedule and to antagonize its customers. Although the principles of conflict theory are applicable in all these spheres of activity, military combat will be used here as the central metaphor for aggressive rivalry.

As an analog to the production function of standard economic analysis, the first section below develops the fundamental idea of a conflict success function. Alternative formulations of the conflict-success function are considered and some of the implications derived. The next section shifts attention from the short run to the long run, allowing early success to translate into greater fighting capacity at later points in time. Following sections address a number of other aspects of conflict technology, among them the distinction between offense and defense, the relevance of the traditional Lanchester analysis of battle, and the question of when and how it could be that "right makes might" (i.e., that the more deserving side has a better chance of winning). The final section summarizes briefly.

CONTEST SUCCESS FUNCTIONS: THE STRUGGLE FOR INCOME

In the domain of conflict, technical experts design guns, bombs, missiles, and so on; military leaders are charged with employing them. These are, in effect, the engineers and business practitioners of the conflict industry. (In nonmilitary conflicts, there are decision makers with corresponding roles: politicians hire speech writers and media consultants, and litigants hire attorneys.) The economist's role is not to replace such professionals but instead to address the *macrotechnology of conflict*, making use of such familiar concepts as increasing versus decreasing returns, economies of scale and scope, and factor substitution.

The central analytical device of economic production theory, the *production function*, takes as inputs amounts of resources such as labor, land, and capital and describes their conversion into desired goods as outputs. Correspondingly, in conflict theory, one contender's military efforts may be more capital intensive, another's more labor intensive. But a less familiar and indeed defining feature of conflict theory is a kind of abstract analog of the production function that might be termed the *conflict success function* (CSF). The CSF takes as inputs the fighting efforts on the two sides and generates as outputs the respective degrees of success achieved.

Military theorists generally distinguish two main modes of combat: attrition and maneuver (e.g., Luttwak 1987, 93-96). *Attrition* is a straightforward matter: one wins by grinding down the enemy's forces faster than one's own. *Maneuver* involves indirection: the aim is to catch the enemy unprepared or outnumbered at a critical point. So a weaker side might, thanks to surprise, win a maneuver battle. Maneuver can to some extent be modeled in terms of game-theoretic mixed strategies, but that line of analysis will not be pursued here. What always remains true is that, at the point of contact, all clashes ultimately come down to attrition. Clever maneuvering consists only of arranging one's forces in space and time in such a way that, should battle eventuate, the attrition rates would favor your side. So I will be concentrating on attrition interactions.

Consider two contenders with given resources R_1 and R_2.[1] Each side will be dividing its efforts between productive activity E_i and appropriative or "fighting" activity F_i. The prize at stake might depend on the parties' productive efforts; for example, it might be the revenue jointly produced by capital and labor within a business firm. But for the moment, let the prize be a fixed quantity Q of income. At this level of generality, no attempt is made to specify in greater detail the elements of fighting efforts as independent variables of the CSF or degrees of "appropriative success" as dependent variables. (In a military context, fighting efforts might be measured by the number of divisions in the field or naval vessels at sea, and success in terms of territory or booty acquired.) Also, unless otherwise specified, risk neutrality will always be assumed.[2] In consequence, proportionate success p_i ($i = 1, 2$) can be interpreted, equivalently, either as the deterministic fraction of the prize awarded to side i or as its probability of total victory in an all-or-nothing contest. (For expository purposes, I will usually be adopting the first of these interpretations.)

A number of formal conditions that should ideally be met by CSFs are described in Skaperdas (1996) and Neary (1997). The first is the so-called "logit" condition (Dixit 1987): that p_1 and p_2 must sum to unity.[3] More formally,

$$p_1 = \frac{\phi(F_1)}{\phi(F_1) + \phi(F_2)} \text{ and } p_2 = \frac{\phi(F_2)}{\phi(F_1) + \phi(F_2)}. \tag{1}$$

Although an enormous range of functional forms for the CSF might satisfy the logit condition, some special cases turn out to be especially useful (just as the Cobb-Douglas and CES formulas have proved to be useful specifications of the standard production function). It will be illuminating to think in terms of two canonical forms: in one class of CSF the success fractions p_1 and p_2 depend on the ratio of the fighting efforts F_1/F_2, in the other on the difference $F_1 - F_2$ (Hirshleifer 1988, 1989).

Starting with the CSF in ratio form, let $\phi(F_i) = (b_iF_i)^m$, where F_i is side i's fighting effort, and b_i is a measure of per unit-battle effectiveness. (If $b_1/b_2 = 2$, then a single side-1 soldier is as effective as two of side 2's soldiers.) Thus,

$$p_1 = \frac{(b_1F_1)^m}{(b_1F_1)^m + (b_2F_2)^m} \text{ and } p_2 = \frac{(b_2F_2)^m}{(b_1F_1)^m + (b_2F_2)^m}, \tag{2}$$

which of course imply

1. Fixed resource endowments are the hallmark of the short-run analysis of this section. In the long-run analysis of the next section, decisions at earlier dates will affect resource availability at later points in time.

2. Conflict is characteristically a highly uncertain process, so attitudes toward risk are likely to play an important role. A military planner might advisedly design a weapon that sacrifices ideal performance for reliability under less favorable circumstances. This article does not attempt to address such issues.

3. However, owing to overconfidence or the reverse, the contenders' *perceived* success fractions might not sum to unity. For example, each side might believe it has an 80% chance of prevailing. Mistaken beliefs are set aside here.

$$\frac{p_1}{p_2} = \left(\frac{b_1F_1}{b_2F_2}\right)^m. \tag{2a}$$

For simplicity in what follows, differences in unit effectiveness will be assumed away (unless otherwise indicated), so let $b_1 = b_2 = 1$. The exponent m plays a crucial role in the analysis: m is a *decisiveness parameter* that scales the degree to which a side's greater fighting effort translates into enhanced battle success. To illustrate, Figure 1 plots side 1's success fraction p_1 as a function of its own fighting effort F_1, the opponent's F_2 being held fixed. The diagram shows that when the decisiveness parameter is low ($m = 0.5$), even a large force preponderance in favor of side 1 does not make its p_1 very much greater than $\frac{1}{2}$. But as the parameter m rises in value, any given force preponderance has a magnified effect on relative success.

For the difference or "logistic" form, let $\phi(F_i) = \exp(kb_iF_i)$:

$$p_1 = \frac{\exp(kb_1F_1)}{\exp(kb_1F_1) + \exp(kb_2F_2)} \text{ and } p_2 = \frac{\exp(kb_2F_2)}{\exp(kb_1F_1) + \exp(kb_2F_2)}, \tag{3}$$

which in turn imply

$$\frac{p_1}{p_2} = \frac{\exp(kb_1F_1)}{\exp(kb_2F_2)}. \tag{3a}$$

Or, rewriting in terms of the *differences* between the fighting efforts,

$$p_1 = \frac{1}{1 + \exp\{k(b_2F_2 - b_1F_1)\}} \text{ and } p_2 = \frac{1}{1 + \exp\{k(b_1F_1 - b_2F_2)\}}. \tag{3b}$$

Once again, except where otherwise indicated, the unit effectiveness parameters will be taken to be $b_1 = b_2 = 1$. In the difference-form version of the CSF illustrated in Figure 2, the coefficient k serves as the decisiveness parameter. As before, a larger k magnifies the greater the extent to which force superiority translates into achieved success.

For the ratio form of the CSF, the curves in panel (a) indicate that for $m \leq 1$, marginal returns to fighting effort F_i are decreasing throughout. But for $m > 1$, there is an initial range of increasing marginal returns, the point of inflection occurring at

$$p_i = \frac{m-1}{2m}. \tag{4}$$

Thus, the ratio form of the CSF implies that diminishing marginal returns always set in before the side making the smaller fighting commitment attains equality with the opponent.

For the difference form of the CSF, the inflection point necessarily occurs at $p_i = 0.5$ exactly. As shown in Figure 2, there are always increasing marginal returns up to the point of force equality $F_1 = F_2$ and diminishing marginal returns thereafter. So although it is always better to have the larger (effectiveness-weighted) legions, under the difference form reinforcement is most welcome when it reverses a force disparity from slight inferiority to slight superiority. For the ratio form, in contrast, when $m \geq 1$,

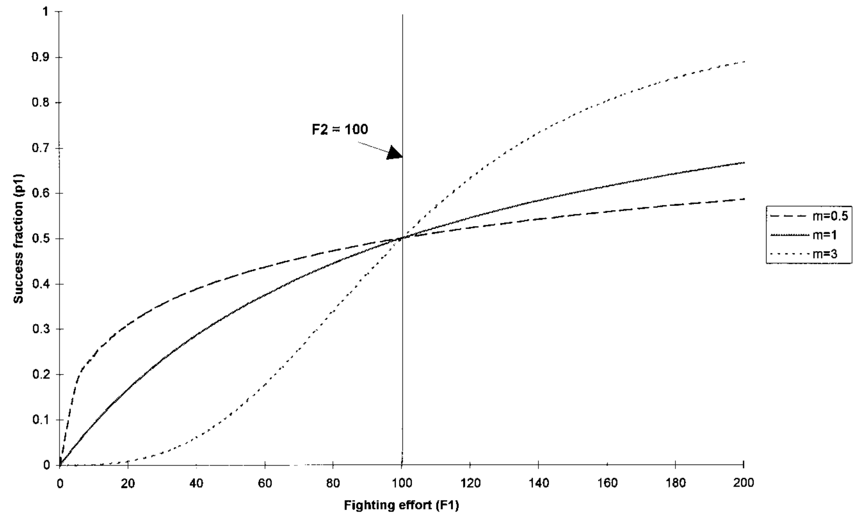

Figure 1: Contest Success Functions: Ratio Form

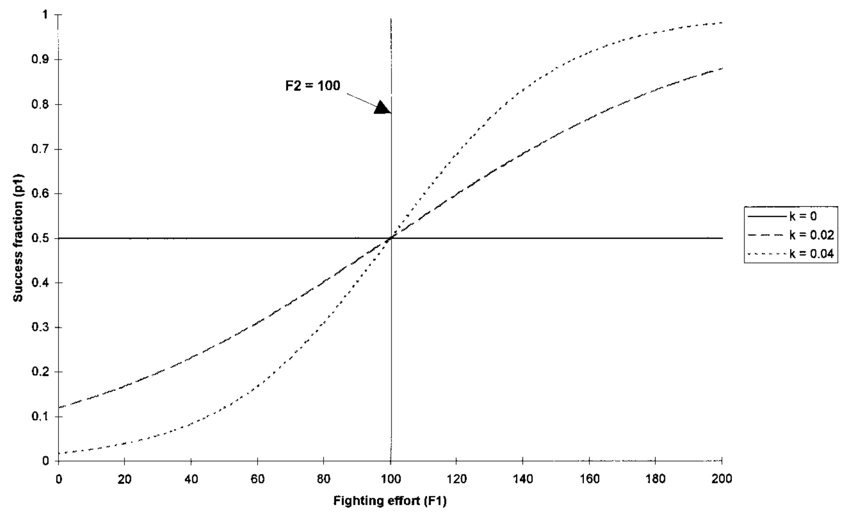

Figure 2: Contest Success Functions: Difference Form

marginal effectiveness is highest for the very first epsilon of effort and in any case is always highest somewhere short of the point when your army attains equality with the opponent's.

The ratio version of the CSF has what might be termed a *forfeiture* feature. Zero-effort F_i always implies zero-success p_i (apart from the indeterminate special case in which both F_1 and F_2 are zero). Refusal to fight means forfeiting any share of the total amount at stake. The difference version of the CSF is less extreme. From equation (3), as illustrated in Figure 2, a player investing zero effort still generally retains some fraction of the prize at stake.

These various considerations help the analyst choose one or the other version of the CSF in specific applications. In litigation, the ratio version is likely to be applicable. An aggrieved party who makes no effort at all (who fails even to file suit) gives up any prospect of success, whereas a respondent who offers no defense must expect an adverse judgment. But in union-management conflict, the difference form is more likely to be appropriate. A trade union, even when in a position to totally dictate pay and working conditions, is likely to limit its demands if only to keep the employer in business. Correspondingly, even the most domineering management may find that market forces make it advisable to offer higher pay and benefits than it might conceivably have insisted on.

Applied to military combat, the ratio form of the CSF corresponds to clashes taking place under theoretically ideal conditions such as full information, absence of fatigue, and a uniform battlefield without topographical features. Then force superiority can be pursued to its limit. But when what Clausewitz termed *friction* plays a role (Rothfels 1943, 103), information can be imperfect, the defeated side may find refuges, and even the victor can be subject to disorganization and exhaustion. So the difference form, in which even a nonresisting side need not lose absolutely everything at stake, is likely to be more applicable.[4]

The military historian and analyst T. N. Dupuy (1987, esp. chap. 10-11) employed the equivalent of a CSF in analyzing military engagements in World War II and the Israel-Arab wars. Although he tabulated and plotted "power ratios" against "result ratios," his data are actually somewhat more consistent with the difference form of the CSF—as would be expected, owing to the influence of Clausewitz's frictional considerations in actual combat. In agreement with Figure 2, increasing marginal returns to the weaker side appear to have held up to the point of equality $F_1 = F_2$, after which sharply decreasing returns to force superiority set in. In a comparison of 93 engagements on the western front in World War II, Dupuy found a force preponderance of 5:1 to be associated on average with a result ratio well under 2:1, which (on either the ratio or the difference interpretation of the CSF) works out to quite a low value of the decisiveness parameter.

Dupuy (1987) employed a multidimensional concept of battle success—specifically, a weighted measure taking into account not only territory lost or gained but also

4. These somewhat conflicting considerations suggest that many real-world contexts might be best modeled by a conflict success function (CSF) that combines elements of the ratio and difference forms. One possibility (adapted from Neary 1987) sets $\phi(F_i) = \eta_i + F_i^m$, where $\eta_i > 0$. Thus,

$$\frac{p_1}{p_2} = \frac{\eta_1 + F_1^m}{\eta_2 + F_2^m}.$$

In this "offset-ratio" formulation, as in the difference form, a contender investing zero fighting effort will still capture a positive fraction of the contestable income. Nevertheless, no particular fraction is ever guaranteed or secure; a sufficiently large F_j on the opponent's part will force p_i toward zero. The ratio η_1/η_2 can be interpreted as the "status quo" situation, the division of the prize that holds when fighting efforts on both sides equal zero.

casualties suffered[5] and allowing in addition for estimated accomplishment of the mission he attributed to the contending forces. In the context studied, declining the engagement entirely (abandoning the territory or position at stake) was usually not totally disastrous. (A side that retreats gives up ground but may reduce its casualties and retain the ability to make a stand at another place and time.) All these considerations support the inference that the *difference form* of the CSF is typically relevant for military battles, with the possible exception of a few rare "do-or-die" situations critical to the overall outcome of the war.[6]

As already indicated, in a full general equilibrium analysis the optimal fighting efforts F_1 and F_2 would depend on the totality of determinants influencing the decisions on the two sides and hence cannot be derived from technology alone. Nevertheless, the following may illuminate ways in which the form of the CSF influences the outcome of conflict.

1. When conditions correspond to "frictional combat," as modeled by the difference form of the CSF, the weaker side may find it preferable to abandon the contest entirely. First because, as noted, investing zero fighting effort need not imply forfeiting everything at stake. And also because, owing to the presence of increasing returns up to the point of equality, the weaker side—if it fights at all—is under strong pressure to make the heavy investment required to match the opponent's fighting effort. In contrast, under "ideal combat" (ratio form of the CSF), zero fighting effort entails giving up any share of the prize.
2. *Total peace*, in which neither side devotes any resources at all to fighting effort, is impossible as an equilibrium outcome when the ratio form of the CSF is applicable—because if $F_1 = F_2 = 0$, either side could then capture the entire prize by an infinitesimal fighting investment. A mutual disarmament equilibrium is possible under the difference form, provided that the value of the decisiveness parameter k is sufficiently low (Hirshleifer 1988, 217-18).[7]
3. Despite the forfeiture characteristic of the ratio form, provided the weaker side puts in *some* fighting effort, it may end up doing relatively well—if the decisiveness coefficient m is sufficiently low.[8] The reason is that, as shown in Figure 1, decreasing returns set in from the very start (for $m \leq 1$) or, at any rate, set in relatively early. So the more powerful side is likely to encounter low marginal payoffs from further investment in fighting effort.

LONG-RUN ANALYSIS: THE SLIPPERY SLOPE

The preceding section considered fighting for a given prize out of currently endowed resources. But these resources themselves are, in each successive period,

5. Weiss (1966) is a somewhat comparable study of U.S. Civil War data, except for analyzing battle results solely in terms of casualties suffered on each side.

6. It might be thought a fatal objection against the difference form of the CSF that a force balance of 1,000 soldiers versus 999 implies the same outcome (in terms of relative success) as 3 soldiers versus 2! That this may seem unreasonable is probably due to the exclusion of idiosyncratic and unmodeled factors that might inject a random element into the outcome. Any reasonable provision for randomness would imply a higher likelihood of the weaker side winning in the 1,000:999 comparison than in the 3:2 comparison.

7. $F_1 = F_2 = 0$ can also be an equilibrium for the offset-ratio form of the CSF described in an earlier footnote, in which case the status quo is preserved.

8. This is the "paradox of power" (Hirshleifer 1991; Durham, Hirshleifer, and Smith 1998).

influenced by fighting success in preceding periods. To cut through the intractable complexities of full intertemporal analysis, let us simplify by assuming that over time the contenders always devote constant *proportions* of resources to the two forms of activity: productive effort and appropriative effort—that is, each side makes an optimal once-and-for-all choice of the "intensities" e_i and f_i:

$$e_i \equiv {}^{E_i}\!/_{R_i} \text{ and } f_i \equiv {}^{F_i}\!/_{R_i}, \tag{5}$$

where, of course, $e_i + f_i = 1$. Choosing a higher productive intensity e_i means that, in the steady-state solution, side i can generate more aggregate income from any given resource holdings. Choosing a higher appropriative intensity f_i means that side i will capture a larger fraction of the available resources. Thus, in the long-run analysis, allowing for conquest of resources means that conflict technology and production technology are inextricably intertwined.[9]

Assume each side i produces income q_i from its own currently controlled resources[10] in accordance with

$$q_i = E_i^h = (e_i R_i)^h. \tag{6}$$

(If $h > 1$, there are increasing marginal returns to productive effort and the opposite if $h < 1$.) As before, the CSF determines the respective success fractions p_1 and p_2, where of course $p_1 + p_2 = 1$. Using the ratio version of the CSF, and assuming as usual that the combat effectiveness coefficients b_i are equal and can be ignored, we can write

$$\frac{p_1}{p_2} = \left(\frac{F_1}{F_2}\right)^m. \tag{7}$$

The long-run success fractions determine the division of the society's aggregate resources R:

$$R_i = p_i R. \tag{8}$$

Using (5) to convert from F_i to f_i units,

$$\frac{p_1}{p_2} = \left(\frac{f_1}{f_2}\right)^{\frac{m}{1-m}}. \tag{9}$$

Equation (9) describes the steady-state relationship between the ratio of chosen fighting intensities f_1/f_2 and the equilibrium success ratio p_1/p_2, which in turn equals the equilibrium resource ratio R_1/R_2. Asymmetries between the players having been ruled out, in any interior equilibrium, $f_1 = f_2$ and consequently $p_1 = p_2$.

Although no analytic proof will be provided here, Figure 3 illustrates that a stable interior equilibrium can exist only for $m < 1$. The ratio of the fighting intensities f_1/f_2 is

9. In addition, productive investment leading to internal economic growth over time is an alternative way of building up long-run military power (Wolfson 1985).

10. To simplify the long-run analysis, joint production is not considered here.

shown on the horizontal axis and the success ratio p_1/p_2 on the vertical axis. As the decisiveness parameter m approaches 1, the curve describing p_1/p_2 as a function of f_1/f_2 approaches a limiting step function such that $p_1/p_2 = 0$ for all $f_1 < f_2$—jumping to $p_1/p_2 = \infty$ when $f_1 > f_2$. Intuitively, when the conflict interaction in any period is sufficiently decisive (i.e., when $m \geq 1$), the contenders find themselves on a "slippery slope." Whichever side chooses the higher fighting intensity, f_i is going to end up controlling *all* the resources.[11] (Or, if the contenders were to chose the same f_i, the resources will eventually be monopolized by whichever side has initially higher R_i.) The central conclusion is therefore: when preponderance of fighting effort is excessively decisive, the inevitable consequence is hegemonic conquest.[12]

It is straightforward to extend the model to any number N of anarchic contenders. In an old-fashioned yet convenient notation, the generalization of equation (9) can be written as follows:

$$p_1 : p_2 : \cdots : p_N = (f_1 : f_2 : \cdots : f_N)^{\frac{m}{1-m}}. \tag{10}$$

Once again, $m < 1$ is necessary to prevent hegemonic takeover. Subject to this qualification, the higher is m, the smaller is the equilibrium "polarity" N.[13]

As an historical illustration, in ancient Greece the multipolar (large N) city-state system was brought to an end by technological improvements that made large-scale naval warfare possible. (Naval fleet battles tend to be highly decisive: the winner commonly crushes the loser and gains command of the seas.) By the time of the Peloponnesian War, practically all city-states had to accept subordination either to Athens or Sparta. Although Sparta's hegemony after its ultimate naval victory in 405 B.C.E. was only temporary, the old city-states were never able to reassert their autonomy. Apart from Alexander's short-lived empire, the next several centuries in the Near East were characterized by an oligopolar system of a few major powers. In this period, it appears, the decisiveness parameter m was high enough to rule out multipolarity but not high enough for effective control by a single hegemon. Only in 146 B.C.E. (dating from the final destruction of Carthage) was Roman supremacy over the Mediterranean world achieved by combined sea and land power.

11. A numerical example may clarify. If the total resources available are $R = 100$, the decisiveness parameter is $m = 2/3$, and if the fighting intensities on each side have been chosen (not necessarily optimally) to be $f_1 = .1$ and $f_2 = .2$, respectively, then from equations (8) and (9), $p_1/p_2 = R_1/R_2 = (.1/.2)^2 = 1/4$, implying that in long-run equilibrium $R_1 = 20$ and $R_2 = 80$.

To illustrate the convergence process, suppose the time-0 resource vector is $(R_1^o, R_2^o) = (60,40)$. The first-period conflict outcome is $(p_1', p_2') = (6/8)^{2/3} = .825$, implying an end-of-period revised resource allocation $(R_1', R_2') = (45.2, 54.8)$. After one more period of conflict, the resource allocation becomes $(R_1'', R_2'') = (35.7, 64.3)$. Evidently, the equilibrium $(R_1, R_2) = (20, 80)$ is being approached asymptotically.

In contrast, for a decisiveness parameter in the range $m > 1$, say, $m = 2$, starting from the same initial resource vector (60, 40), the first- and second-period reallocations would become (36.0, 64.0) and (7.3, 92.7). The process rapidly diverges in favor of the side with the higher f_i.

12. A high decisiveness parameter is of course not the only factor tending to promote hegemonic takeover. Cederman (1994) discusses, among other factors, offense/defense advantage and alliance formation.

13. This analysis postulates a mêlée—a war of all against all. (Allowing for coalitions would take us too far afield.)

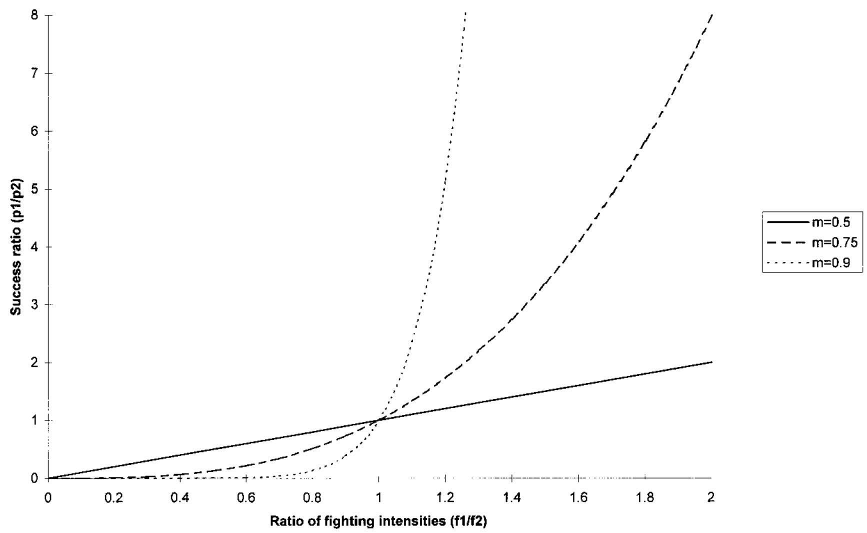

Figure 3: The Decisiveness Parameter and Dynamic Stability

Going outside the domain of military struggles, the constitutions of states are often designed to protect minorities and thereby prevent one-sided political hegemony. Bills of rights and separation of powers reduce the decisiveness parameter *m* applicable to political conflict, so a successful electoral campaign does not give the winner total carte blanche. If there were no such limits on majority supremacy, i.e., if the CSF applicable to electoral contests were winner-take-all, partisan politics might well approach a fight to the death. ("Constitutions that are observed and last for a long time are those that reduce the stakes of political battles" [Przeworski 1991, 36].)

THE LANCHESTER MODEL OF BATTLE

The CSFs dealt with so far represent the macrotechnology of conflict interactions, analogs of the familiar CES or Cobb-Douglas functions of production theory. Military theorists, to the extent they have engaged in rigorous modeling at all, have for the most part not looked at conflict technology in this way. Instead, they have mostly concentrated on the fine structure or *micro*technology of unit-on-unit battles. The best-known model in the military literature, due to Lanchester (1976), deals with attrition rates of military forces in an engagement.

The simplest version of the Lanchester equations can be written:

$$\frac{dF_1}{dt} = -\kappa_2 F_2 \text{ and } \frac{dF_2}{dt} = -\kappa_1 F_1, \tag{11}$$

where the F_i are the force sizes and the κ_i are unit "kill probabilities." Thus, each side's casualty rate is proportioned to the enemy's force size and kill probability. Lanchester associated these equations with the conditions of "modern war," i.e., where the range of weapons makes each and every enemy unit or soldier equally vulnerable to each and every friendly weapon. (What Lanchester called "ancient war," in contrast, consists of one-on-one battles in which the larger force cannot concentrate fire on the smaller number of enemy targets. Thus, for ancient war, the attrition rates on both sides are linearly proportioned to the size of the smaller enemy force.)

The implied state equation (where $\overline{F}_1$ and $\overline{F}_2$ are the initial sizes of the contending forces) is[14]

$$\kappa_1\left(\overline{F}_1^{\,2} - F_1^2\right) = \kappa_2(\overline{F}_2^{\,2} - F_2^2). \tag{12}$$

If, for example, it is believed that the enemy will collapse at 50% casualties then, given the magnitude of one's own superior force, equation (12) shows the friendly casualties that would be incurred in reaching that breakpoint. Or, a military planner might calculate how much more cheaply that end could be achieved by starting with a larger friendly force.

It also follows that fighting strengths are proportional to the squares of numerical strengths.[15] This is of particular relevance in calculating the power of divided forces (e.g., kill probabilities being equal, a force of five is equivalent in strength to two separated detachments of three plus four). The implication is that a smaller army might be able to successively defeat separated contingents of a larger enemy force.

The Lanchester "microtechnology" equations are related to the CSF in ratio form. The kill probabilities κ_i correspond to the unit effectiveness parameters b_i in equation (2a) and the initial force sizes $\overline{F}_1$ and $\overline{F}_2$ to the committed fighting efforts. The squaring in equation (12) plays a role somewhat analogous to the decisiveness parameter m. (In Lanchester's ancient war condition, squaring would not hold, so numerical superiority would be less decisive.)

Hembold (1965) has extended the Lanchester model to allow for diminishing returns to larger force size. In his version, somewhat reminiscent of the Cobb-Douglas production function, equation (11) would become

$$\frac{dF_1}{dt} = -\kappa_2 F_1^{\lambda} F_2^{1-\lambda} \text{ and } \frac{dF_2}{dt} = -\kappa_1 F_2^{\lambda} F_1^{1-\lambda}, \tag{13}$$

where $0 \le \lambda \le 1$. (When $\lambda = 0$, this reduces to the simple Lanchester formulation.) Thus, casualties would in general be an increasing function of one's own force strength as well as of the enemy's.

14. From (11), we have $dF_1/dF_2 = \kappa_2 F_2/\kappa 1 F_1$, or $\kappa_1 F_1 dF_1 = \kappa_2 F_2 dF_2$. Integrating both sides, we have $\kappa_1 F_1^2 = \kappa_2 F_2^2 + C$, where C is a constant of integration. Evaluating the constant by substituting the initial values $F_1 = \overline{F}_1$ and $F_2 = \overline{F}_2$ leads to the equation in the text.

15. When $\kappa_1 \overline{F}_1^{\,2} = \kappa_2 \overline{F}_2^{\,2}$, then $\kappa_1 F_1^2 = \kappa_2 F_2^2$. The forces are equally matched, in the sense that reciprocal attrition drives them toward zero simultaneously (should the battle proceed to the limit).

A crucial limitation of Lanchester-type models is that the stronger side must ultimately wipe out the weaker, so there is no way to scale *degree* of success.[16] It is true that battles do sometimes go to the limit—total victory for the one side, total defeat for the other. But most do not. Wars, being more extended in both time and space, are even less likely than battles to have such a categorical outcome. Or, to take a nonmilitary example, in any given electoral year, one party may sweep the positions up for vote, but in the longer run the parties may share the benefits by alternating in office. Put more generally, microincidents are more likely to have extreme outcomes than macroevents that tend to involve some degree of averaging or smoothing. Our interest here is more in the big picture, for which the macrotechnology of conflict is more relevant.[17]

OFFENSE VERSUS DEFENSE

Military analysts have mainly been concerned with the *tactical* distinction between offense and defense. Students of international relations (e.g., Quester 1977; Levy 1984) have addressed that question also on the level of war aims and strategy. In this larger sense, the offense seeks to gain something of value possessed by the opponent, whereas the defense is supposedly satisfied with the status quo. The strategic and tactical concepts do not exactly correspond. A combatant on the strategic defense might still use offensive tactics, for example, by attacking preemptively. And the strategic offense, to concentrate strength at the specific point of attack, is likely to remain on the tactical defensive everywhere else.

Owing to its forward movement, the tactical offense necessarily suffers from exposure to fire and thus incurs adverse per-unit "kill probabilities" in Lanchester's sense.[18] A familiar military rule of thumb is that to win, the offense needs to have three times the numerical strength of the defense.[19] But on the other hand, the offense chooses the specific time and place of attack. Given this degree of freedom, the offense aims to concentrate the required force preponderance at a particular point or sector. Thus, improvements in mobility (e.g., invention of the internal combustion engine) favor the offense,[20] whereas irregular terrain tends to favor the defense.[21]

But once again, it is the strategic level of analysis that corresponds more closely to the macrotechnology of concern here. On that level, the traditional international-rela-

16. Although the time it takes and the casualties suffered in the process do measure some of the costs incurred in gaining victory.

17. For further analysis of Lanchester models, see Anderton (1992) and the references provided therein. The prospects for microanalytic modeling of combat are subjected to careful realistic criticism in Stockfisch (1975).

18. A number of authors have adapted Lanchester's basic model to this effect, including Brackney (1959) and Anderton (1992).

19. The possible justification and range of validity of the 3:1 rule of thumb have been discussed by, among many others, Dupuy (1987) and Brackney (1959).

20. Of course, defenses may themselves be more or less mobile. But the tactical defense generally aims at holding a fixed position (which can then be strengthened, for example, by fortification).

21. Terrain may be irregular not only in the topographical sense but also in terms of value considerations—military or political or economic. Some locations may be of such critical value as to necessarily channel the assault toward their capture, a consideration that lessens the offensive advantage of being able to select the point of attack.

tions distinction between the strategic offense and defense, that the one side seeks change whereas the other is satisfied with the status quo, is faulty. In some instances, that may substantially be the case. But more generally, each side will have a range of goals from minimal to maximal. In the absence of opportunity to do any better at acceptable cost, a contender may well be satisfied to preserve the status quo. But if the balance of forces were to shift in its favor, that same contestant would likely seek to improve its situation. The leaders of the French revolutionary forces, having won their defensive battle against incursions by Prussia, Austria, and other traditional continental powers, then shifted to the offensive and invaded Germany, Italy, and the Low Countries. Analytically, it is preferable to allow either side to take the offensive (to seek a revision in its favor)—and indeed to allow for the possibility of *both* sides doing so in sequence or simultaneously.

Assume that, as in equation (6), each side has generated separate income q_i by means of its own productive effort E_i. However, this produced income is subject to capture by the opponent. In effect, then, there are two battles. In the first battle, contender 1 as defender retains the share p_{11} of its own production q_1, that share being a function of its own "guarding" effort G_1 and the opponent's "attacking" effort A_2. In the second battle, side 1 as attacker appropriates the fraction p_{12} of the opponent's production q_2. Thus, p_{11} and p_{22} are the *retained* shares and p_{12} and p_{21} the respective *appropriated* shares.

The outcome can be represented as a transfer T_{ij} from side j to side i, the net balance of the appropriated shares (cf. Skogh and Stuart 1982, 30):

$$T_{ij} \equiv p_{ij}q_j - p_{ji}q_i. \tag{13}$$

Of course, $T_{ji} \equiv -T_{ij}$.

So each side is on the offense in one battle and on the defense in the other (as in strategy games such as chess or "go," where a player might be attacking at one side of the board and defending elsewhere).[22]

To allow now for offense versus defense advantage, recall the "battle effectiveness coefficients" b_1 and b_2 of equation (2). Instead of differences between the combatants, we now want to parameterize differing effectiveness between the offensive and defensive *roles* (assuming the contending forces are otherwise equivalent). And specifically, a_i will signify combat effectiveness in the offensive (attacking) role and g_i in the defensive (guarding) role. Continuing the parallel with the ratio CSF of equation (2), there now is a CSF for each of the two battles. The overall success of contestant 1 is given by

$$p_1 \equiv p_{11} + p_{12} = \frac{(g_1G_1)^m}{(g_1G_1)^m + (a_2A_2)^m} + \frac{(a_1A_1)^m}{(g_2G_2)^m + (a_1A_1)^m}. \tag{14}$$

22. Grossman (1998) analyzes a CSF that provides for the relative advantages of defense and offense. However, that paper has one combatant entirely on the offense, the other entirely on the defense. Closer to the analysis here is an unusual application of offense-defense analysis to a paternity-seeking "mating game" (Hawkes, Rogers, and Charnov 1995). Each male divides his time between "offense" (pursuing extra-pair matings with other females) versus "defense" (guarding his own mate against similar efforts by other males).

Corresponding equations hold also for contestant 2, where $p_{21} \equiv 1 - p_{11}$ and $p_{22} \equiv 1 - p_{12}$. Side 1's per-unit defense advantage in its defensive battle is g_1/a_2, and g_2/a_1 is interpreted similarly as side 2's defensive advantage.

Historically, the number, size, and political structure of independent states have been heavily influenced by the relative pace of improvements in offensive and defensive technology. It is commonplace that the Middle Ages, with its feudal castles, was a defense-dominated era. Starting some time after 1400, the introduction of cannon able to knock down castle walls shifted supremacy to the offense. In a later period, the increasing deadliness of firearms, as demonstrated in the American Civil War and culminating in the machine gun of World War I, gave primacy to the defense—only to have the balance reversed once more owing to the advent of mobile armor in World War II. Once again, however, it is necessary to keep in mind the macro-micro distinction. In the Civil War, defense dominated in battle but less clearly so in the overall war. Railroads and steamships made it possible to project military force over great distances, making it possible for the North to penetrate the Confederacy's heartland. But conversely, in World War II, German mobile armor, although unprecedentedly effective on the geographical scale of northern France, bogged down in the vast expanses of Russia.

Setting aside these often-discussed historical questions, there is a subtler distinction scarcely noted in the literature: between *defense-dominated* warfare and *indecisive* warfare. That is, between situations in which the advantage ratio g_i/a_j is high (favors the defense) as opposed to situations in which the decisiveness coefficient m or k is low (a consideration that minimizes the advantage accruing to the more powerful combatant, whether on offense or defense). Phalanx warfare in ancient Greece is sometimes described as defense-dominated but was actually only indecisive. There was no clear distinction between offense and defense: the armies mainly pushed at one another, and the loser could usually escape to fight again another day (Preston and Wise 1979, 17). Owing to the ineffectiveness at that date of missile weapons and the limited scope for cavalry in hilly terrain, it was hardly possible for the stronger side to impose the highly *disproportionate* casualties that make for decisive victory. In naval warfare as well, very often the offense-defense distinction hardly applies. Yet, in contrast with ancient phalanx warfare, naval battles are likely to be quite decisive. Even when the initial forces are closely matched, the winning side can come close to annihilating the loser—as occurred at Trafalgar in 1805 and Midway in 1942.

Clausewitz asserted that although the defense may have an advantage in battle, only the offense can ever be decisive.[23] That might be true if the criterion is immediate territorial gain: a side that merely stands fast cannot occupy the enemy's domain. But the payoff of battles may include other elements—notably, ability to wage future war. In this larger sense, many defensive battles have been highly decisive, among them Poltava in 1709 and Waterloo in 1815.

Certain paradoxical aspects of offensive versus defensive warfare have become central to modern international relations in the nuclear era. The basic technological fact is that nuclear weapons make it far cheaper to inflict damage than to ward off damage. In consequence, at least according to standard doctrine, the only effective way to

23. von Clausewitz ([1832] 1984), especially Book VI, Chapter 5.

achieve the latter aim is by threatening to do the first. So even a purely defensive war aim seems to require an offensive tactic.

Although a full analysis would take us too far afield, the "solution" to this problem adopted in the period of Soviet-U.S. confrontation—at least on the U.S. side—was the so-called mutual assured destruction (MAD) policy. Under MAD theory, each side deters the other by the threat to wreak unacceptable retaliatory damage. MAD requires that both contenders invest in defense *only* to the extent of guaranteeing the survival of a sufficient portion of its attack force. Even a few surviving weapons, given their huge damage-inflicting potential, were expected to impose unacceptable retaliatory damage on the war initiator. Under the paradoxical MAD logic, attempting to defend one's cities and population is provocative; accumulating nuclear attack weapons is not.[24]

On the other hand, nuclear defense has always been much more feasible against small or ragged attacks that might be launched by accident, by irregular or terrorist forces, or by rogue states. Furthermore, the MAD retaliatory threat may be of limited applicability in deterring such assaults. For these reasons and with the waning of bipolar contention, at least a circumscribed nuclear defense is becoming increasingly attractive (McGuire 1992).

GEOGRAPHY

Mountains and jungles, by providing refuges, make force superiority less decisive. Owing to limitations on visibility, such environments also favor tactics of maneuver over sheer attrition—and hence provide a comparative advantage for guerrillas as opposed to regular troops.

As already mentioned, distance makes for diminishing returns to the projection of military power (Boulding 1962, chap. 12-13). On the other hand, there often is an element of increasing returns as well: conquered land areas may contain resources convertible into military power. Just as resources appropriated in one time period can enhance fighting power later on, captured territory may facilitate further conquests (Findlay 1996). Notably, the Romans' ability to convert conquered lands into support areas for further expansion allowed them to overcome the geographical diminishing returns imposed by the transport facilities of ancient times. And similarly, Britain's captured overseas bases were essential to its achieving command of the seas. This "avalanche effect" does not imply that one contender is necessarily bound to become all-powerful. It does mean that a low value of the decisiveness parameter m may be needed to ward off such an outcome.

ORGANIZATION

Other things equal, larger armies defeat smaller ones. But the larger the army, the more urgent the need for organization. Disrupting the enemy command and

24. For varying views on these topics, see, among many others, Kahn (1965), Schelling (1960), Wohlstetter (1959), McGuire (1967), and Intriligator and Brito (1984).

control structure and its internal division of labor may be more efficacious than killing soldiers.

Several aspects of effective organization take on special salience in conflictual contexts.

PRISONER'S DILEMMA AND INCENTIVES

"The collectively rational thing to do is to stay and fight, the individually rational thing to do is to run" (Brennan and Tullock 1982, 228). Like all aphorisms, this one is somewhat oversimplified yet captures an important element of the truth. A prime purpose of military organization is to overcome this dilemma by suitable rewards and penalties, combined with competent monitoring.

DIVISION OF LABOR

In deciding how to divide (and conversely how to combine) tasks, the military context imposes a special need for *sturdiness*. The structure must continue to function in the face of likely casualties and enemy attempts at disruption. Such considerations place a premium on substitutability of personnel and roles, ruggedness of information networks, parallel backup systems, and flexibility of response to changing situations.

COMMAND

Civilian organizations, even relatively dictatorial ones, involve some degree of shared governance. Business firms have their CEOs but also their boards of directors. In battle, however, it is almost universal to have a single officer in command: battles cannot be directed by committee. But *wars* are more protracted and diffuse operations than battles, and their management almost always provides for checks and balances among many individuals and opinions. How to balance the short-run need for rapid command decision with the longer run advisability of considering varied opinions and multiple goals is a permanent problem for conflict technology.

CAPITAL, LABOR, AND OTHER INPUTS

The traditional arguments of economic production functions—land, labor, capital, and so on—do not directly enter as inputs into the CSF employed above. They do enter one step back, as determinants of "fighting effort" (heretofore treated as an unanalyzed black box).

Contender *i*'s aggregate fighting effort F_i would typically be a function of inputs such as military manpower and capital equipment. Manpower might be further disaggregated into combat versus logistic support personnel and equipment into categories such as weapons, munitions, transport, supplies, and so on into smaller and smaller categories. Or on a different basis of classification, land and sea and air forces might be distinguished as elements entering into overall military power.

One important issue is the degree to which capital, and the modern technology that goes with it, can substitute for manpower. Consistent with its superior wealth, the U.S. tradition has been to equip military forces lavishly in the hope of economizing on casualties. The degree of success achieved thereby is not entirely clear. Stockfisch (1976, 63) suggests that goal was not achieved in the Korean War and especially not in the Vietnam War. On the other hand, the Gulf conflict appears to have been a triumph of technology over numbers, perhaps because the terrain was more favorable to mechanization.

As for technology, it was growing overall productivity that made it possible for all the powers, starting in the 19th century, to divert large fractions of their male populations into the fighting forces. In the American Revolution, Washington rarely had more than 10,000 men under command. By the time of the Civil War, the economies of the North and the South were able to support millions of men in the armies.

Although it would take us too far afield to study this topic in depth, the need or desire to acquire resource inputs has historically been a major motive for war. That national economies can overcome resource deficiencies via trade is a standard proposition of economics. For example, in the colonial period America traded agricultural products (land intensive) to England in return for manufactured goods (capital intensive). But the central theme here has been that resources can also be acquired through aggression and appropriation. In what might be termed the *Malthusian theory of warfare*, expanding populations outgrow their resource base and look around for new lands—driving away or liquidating the previous inhabitants (Colinvaux 1980). Examples include tribal warfare in the highlands of New Guinea (Meggitt 1977), the European conquests of the Americas in early modern times, and possibly Germany's 20th-century demands for *lebensraum*. And raiding for slaves—sometimes together with their land, sometimes without—goes back to the earliest days of warfare.

RIGHT VERSUS MIGHT: DOES FORCE ALONE DETERMINE CONFLICT OUTCOMES?

The Sophists maintained that "might makes right." Can it ever be that "right makes might"? That is, can having truth or morality or reason on your side help win battles? The answer must be yes, if (to mention only one possible consideration) soldiers fight more effectively for a cause perceived as just. However, it may not be immediately clear how intangibles such as truth or justice can be factored into conflict success.

To illustrate in a nonmilitary context, consider civil litigation. The contending parties are plaintiff (P) and defendant (D), and imagine there is a fixed prize in the form of a sum of money at stake. Then, it has been proposed that the parties' relative prospects of success p_P and p_D can be summarized by a "litigation success function" such as[25]

$$\frac{p_P}{p_D} = \left(\frac{F_P}{F_D}\right)^{\alpha} \left(\frac{Y}{1-Y}\right)^{\beta}. \tag{15}$$

25. Hirshleifer and Osborne (Forthcoming). Somewhat analogous formulations appear in Katz (1988) and Kobayashi and Lott (1996).

Equation (15) extends the ratio form CSF of equation (2a), with the effectiveness coefficients b_i ($i = P, D$) set at unity. Here "fighting efforts" F_i would represent expenditures on lawyers and other inputs into the legal battle, and the exponent α corresponds to the decisiveness parameter m. The new element in the picture is a parameter Y that signifies the defendant's *degree of fault*, here measured on a scale from 0 to 1. Thus, Y and $1 - Y$ represent the worthiness of the case on each side. The underlying assumption is that "merit" is an element entering into litigation outcomes, quite distinct from "pressure" (the balance of efforts invested). In parallel with the parameter α that scales the decisiveness of the pressure ratio, the parameter β calibrates the decisiveness of merit in determining the outcome of trial. As for why merit plays a role in litigation outcomes, even a cynic must concede that it is generally easier to find valid arguments and supporting evidence for a true proposition than for a false one.

Furthermore, pressure and merit have analogs in other conflictual domains, among them political struggles and contests for commercial advantage. In elections, voters' choices are of course influenced by partisan pressures in the form of propaganda and social influence. But merit generally also has persuasive power: voters have some capacity to arrive at independent judgments. Much the same holds for commercial contests. Consumers are swayed by uninformative advertising and other marketing pressures, yet retain some ability to form valid judgments as to which is the better product.

Turning back to warfare, belligerents, even in this quintessential domain of force and pressure, nevertheless almost always do claim to be fighting in a just cause. Such claims would not be made were it not believed that perceptions of truth and morality do influence the outcome. Why is that the case? To some extent, a warring nation may hope to win favor with neutral powers. But that would hardly explain (to mention one rather absurd instance) Germany's claiming that it was Poland that first attacked in 1939. The only persons likely to lend any credence to such a claim were the Germans themselves, or some of them at least. However cynical, even the Nazis believed that, to some degree at least, perceived merit contributes to fighting power: "right makes might."

BRIEF SUMMARY

Decision makers in all domains of life balance between two classes of economic activities: (1) producing useful commodities for self-use or else for purposes of mutually advantageous exchange versus (2) appropriating goods or resources from other parties (and defending against similar efforts on their part). Correspondingly, two distinct technologies must be distinguished: the familiar technology of production and exchange on one hand, and the technology of conflict and struggle on the other. The general principles of conflict technology apply not only to military combat but also in such domains as redistributive politics, strikes and lockouts, litigation, and crime.

In conflict theory, the analog of the production function is the conflict success function (CSF), which takes as "inputs" the fighting efforts on the two sides and generates as "outputs" the respective degrees of success achieved. Two canonical forms of the

CSF, one depending on the ratio of the fighting efforts F_1/F_2 and the other on the difference $F_1 - F_2$, correspond to the "stylized facts" of differing observed forms of conflict. In either case, a crucial determinant of the outcome is the *decisiveness* parameter, which scales the degree to which force preponderance translates into differential success. Especially in the long run, because success tends to feed on success, a hegemonic outcome is likely unless the decisiveness parameter is relatively low.

Although the central interest here is the macrotechnology of conflict, some attention was paid to microtechnology in the form of the Lanchester equations of battle. These equations correspond to a simplified version of the CSF in which the stronger side inevitably gains total victory. Among the extensions considered were distinguishing between offense and defense (with application to deterrence of nuclear war) and allowing for the effects of geography and organization. Finally, it was shown to a degree that "right makes might." That is, intangible considerations such as truth or morality might well promote success in the technology of conflict.

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